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Wonders of Plant Life

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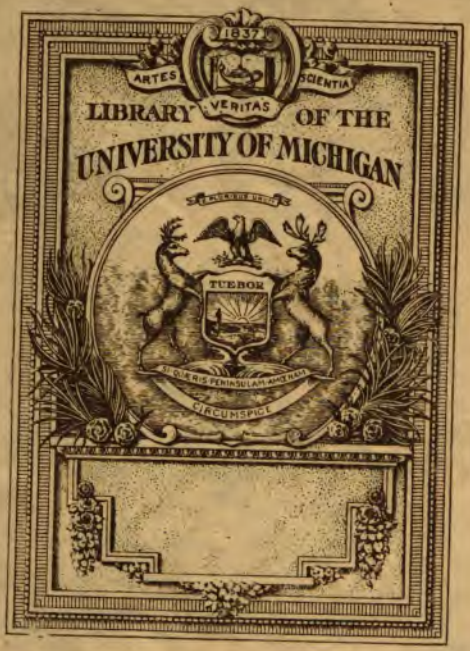

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THE

WONDERS OF PLANT LIFE

UNDER THE MICROSCOPE

BY

MRS. SOPHIE (BLEDSOE) HERRICK

NEW YORK
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PREFACE.

IN throwing together these separate studies in Plant Life, it has seemed best, while revising those already published, to add several chapters on subjects which should help to fill up the larger gaps in the series. No attempt is made to complete the series: the only thing aimed at is to give the more important types in a popular way, avoiding technicalities where ordinary language could be substituted, and where it could not, giving clear explanation of the terms.

It may be objected that an undue space has been allotted to the insectivorous plants: this was done, because so little has ever been attempted, beyond a few magazine articles, to popularize Darwin's work in this direction, and because the subject in itself is so curious and interesting.

The chapters and parts of chapters added to those already published in *Scribner's Monthly*, are Fungi and Lichens, Mosses, Corn and its Congeners, and Orchids. Part of the chapter on Fungi was published some yeas ago in the *Southern Review*.

S. B. HERRICK.

BERGEN POINT, N. J., *Sept.*, 1883.

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WONDERS OF PLANT LIFE.

CHAPTER I.

THE BEGINNINGS OF LIFE.

IN the ebb and flow of thought so characteristic of our modern intellectual life, one idea has many times gained, and as often lost, ground. From the days of Galileo to the present, during the centuries which have elapsed since the gift of its new vision had been bestowed upon the world by the blind Florentine, the doubt has now and again found voice, whether even Divine love and care can be commensurate with Divine power. The infinite reaches of space, revealed or suggested by the telescope, exhausts our capacity for belief. We stagger before the thought of an Intelligence which can and does fill every portion of this infinity of worlds with full, perfect, and exquisite life. The subtle scepticism of the human heart, ever ready to seize an occasion, again asserts itself.

The attribute of power is magnified at the expense of the no less Godlike attribute which is satisfied with nothing less than perfection in detail. The world in its innate unbelief returns to the thought that even a love, a wisdom, a forethought which it mocks with the title of Divine, will fail to bestow upon each atom of this infinity, the care and tenderness which the race, in its infancy and ignorance, had fancied to be its own. And so God is pushed back and away from our human lives into a vague and dim abstraction, as the First Great Cause, and nothing more.

But "Wisdom," now as of old, "is justified of her children." Science is always its own antidote, and is ever ready with the solution of the difficulties which it has raised. A little waiting, and the tubes and lenses, the mechanical perfection and delicate adjustments which had created the doubt, resolved it. While the telescope was sweeping the fields of space,—bringing within the ken of man new worlds, and systems of worlds in the universe of unknown vastness above us,—the microscope, in its humbler sphere, was revealing a no less wonderful universe of unknown beauty and perfection beneath us.

The line of telescopic discovery sweeping off into infinite space might well bring doubt and despair to the mind which contemplates that alone; but there is another line of discovery more beautiful, more wonderful still. As we look and tremble at the Divine power which holds the heavenly bodies in their orbits, we see it come circling round and beneath us, holding us safe within the magic bounds of that Divine love which has made man the central fact of creation.

This little instrument, then, has wrought a noble work for God and truth in the world. The microscope has, apart from its own peculiar work, a mission. Not only has it revealed to us many secrets which make life easier, which soften the pangs of disease and diminish the anguish of bereavement, but it has helped to silence the voice which was delivering its message of desolation to the world, in denying the Fatherhood of God. Not only does it show us the marvellous precision of inorganic nature, and the delicate adjustments of chemical, physical, and vital forces of organic, but it brings us into the very antechamber of that court where life holds its mysterious sway,—almost into the presence of the subtle vital force which baffles analysis, and laughs synthesis to scorn.

Let us begin at the very foundation of life, at its humblest manifestation, at the single stone, as it were, out of which all the magnificent architecture of organic nature is constructed. From the lowest form of life to the highest, from the most delicate sea-weed driven hither and thither by every passing ripple, up through the myriad forms of vegetable and animal life to man himself, there is no exception to the law which associates life, and all its functions, with the cell. In Nature's infinite variety there is nothing half so wonderful as the unity which underlies it all. The ideal type is still adhered to, throughout the numberless modifications of cell life. While there are cells of every size and shape, cells for the performance of every function of life, cells which go to make up every kind of tissue, yet, it is true, that every organic structure is in the main an aggregation of mere cells.

Vegetable cells, in the earlier stages of their development, generally approximate to the sphere in form. As they grow older, assume different offices in the economy of the plant, or are pressed upon by surrounding cells, the shape becomes changed. Each perfect vegetable cell is, in its earliest form, a sac of cellulose, filled with a mass of albuminous

jelly in which is embedded a roundish body,—the nucleus,—chemically like the surrounding jelly. The wall of cellulose (which is the substance afterward transformed into wood) constitutes the main feature by which vegetable are distinguished from animal cells.

Nothing could look more innocent than the contents of a vegetable or animal cell, and yet this harmless jelly is responsible for much bitter and rancorous warfare; it is the much-berated protoplasm,—"the physical basis of life." The name protoplasm, meaning first form, or first mould, has been given, because no form of life, vegetable or animal, fully developed or in embryo, has ever been found dissociated from it.

The protoplasm of a vegetable cell at first entirely fills the cellulose sac; as the cell wall grows the jelly-like mass is seen to give way under the strain, and certain vacancies, called vacuoli, make their appearance, which become filled with cell sap. More and more of these liquid drops appear throughout the mass of protoplasm; they generally coalesce at last, and form a central cavity, while the jelly is merely a lining membrane to the cellulose, or stretches itself across the cavity in the

form of threads or bands. When this stage has been reached, in cell development, the protoplasm is called the primordial utricle. [See Fig. 1.]

As internal cells grow older the protoplasm disappears, the cellulose lignifies, and a mere framework of woody cells is left. The moment the protoplasm disappears the cell is dead, no new material is formed, no fresh chemical combinations

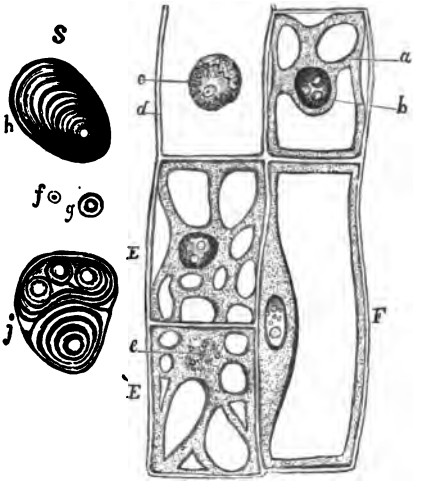


FIG. 1. VEGETABLE CELLS AND STARCH GRAINS.

Parenchymal cells formed from root of *Fritillaria imperialis*, longitudinal section of young cells near apex of root; *d*, cellulose tissue forming cell walls; *a*, protoplasmic contents of cells and spaces holding cell sap; *b*, nucleus; *e*, nucleus swollen by absorption of water *F*, an older cell in which the protoplasm has contracted, leaving a large vacuolus filled with cell sap, and itself forming the lining protoplasmic layer of cell wall sometimes called *primordial utricle*. *S*, *f*, *g*, *h*, *j*, Starch grain in successive stages of growth or accretion.

take place, and the cell neither grows nor subdivides. In the soft albuminous jelly resides the power, so marvellous and inexplicable, which we call life; within it go on all the processes of vitality and reproduction; from it is formed the cell sap, which is the vital fluid of the plant. It is true that the water of the cell sap is absorbed from outside, and yet it always passes through the protoplasmic layer, and in so doing receives from it certain substances which endow it with the power to fulfil its functions.

Protoplasm is more or less capable of pouring or flowing like a liquid, in proportion as it has absorbed more or less water; but it is never in any true sense a fluid. It is endowed with forces which give it the capacity for both an external and internal variability, present in no other known substance. In consequence of the force inherent in living protoplasm, a mass of the structureless jelly (for such it seems to be) may assume a definite external form, it may vary that form, and it may secrete matter having different chemical and physical properties according to definite laws. It is the immediate cause of cell formation, and of every process of organic life, wherever vitality is present.

The cellulose, cell sap, and nucleus are mere differentiations of matter already present in the protoplasm. In some of the lower algæ, or water-plants, a mass of protoplasm escapes from its old cell wall, clothes itself with a cellulose envelope, develops a nucleus, and becomes in all respects like the parent cell. In passing out from its old cell wall, the jelly-like mass assumes a variety of forms; it shows itself to be soft, extensible, and inelastic. As soon, however, as it frees itself from external modifying conditions, it assumes a definite shape in obedience to some internal controlling power.

Certain portions of the protoplasm in most vegetable cells detach themselves and become colored; these are the chlorophyll bodies which give the green color to vegetation, and which, under the controlling power of light, perform the most important of the vital functions. The protoplasmic masses which are associated with the coloring matter are found to retain, not only their shape but also their former volume, after the chlorophyll is abstracted. Each chlorophyll body is therefore composed of two substances, the coloring matter and its protoplasmic vehicle. In most cells the

chlorophyll bodies are irregularly distributed throughout the jelly, but in some of the lower seaweed they assume the form of spiral bands, and in others, of delicate star-like figures. [See Fig. 2.]

The mystery of cell life, which is all life in epitome, has hardly been touched. Though many cells are so small that 125,000,000 may easily be included within a cubic inch of space, yet the work of life goes on no less perfectly in one of these cells than it does in higher organisms. The living jelly in each cell receives crude, mineral matter, absorbs and assimilates it, bringing into existence, by the alchemy of its touch, the material without which all animal life

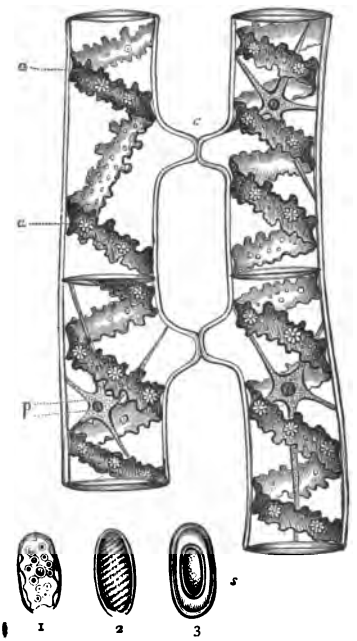


FIG. 2. SPIROGYRA LONGATA ABOUT TO EFFECT CONJUGATION.

a, Spiral bands of chlorophyll containing flower-like aggregations of starch grains and drops of oil; *p*, protoplasm, with nucleus, sending threads across to cell walls; *c*, protuberances of cell wall in preparation for conjugation. [After Sachs.] S_1, S_2, S_3, spores of *S. Longata* in successive stages after conjugation. [After Henfrey.]

would perish. Besides the cell contents already mentioned, which are integral parts of the cell itself, we find the products of its vital processes; quantities of assimilated matter are stored up for the future use of the plant, such as sugar, oil, and, above all, starch. This latter generally makes its appearance in the chlorophyll bodies, and grows till it fills the space, a fine green coating covering the outside of the starch grains. In old, yellow leaves, the coating of green disappears, and the starch grains take the place of the chlorophyll bodies. In the fall of the year all the assimilated material of the leaves is transferred to the perennial parts of the plant, a cicatrix forms across the stem, the leaf falls gently away, leaving the stem healed over before the severance is effected.

The starch grains, which are at first spherical, grow unequally; the layers, which at first form concentrically, are developed afterward only on one side; the shape in consequence changes from spherical to oval, as may be seen in Fig. 1, *h*. Portions of the protoplasm also assume curious crystalline shapes, cubes, tetrahedra, octohedra, etc., not very definite in their form. The crystalloids give the chemical reactions of protoplasm; and

they take up coloring matter, coagulate, and imbibe water so freely as to lose their angularity. They are not at all of the nature of those true crystals, generally of calcium oxalate, or calcium carbonate, which are found in many vegetable cells.

The cell wall enclosing each tiny mass of living jelly is very marvellous in the delicacy and beauty of its structure. As the contents of the cell grow, the cellulose envelope increases by a process which is universal throughout organic nature; particles of cellulose, held in suspension by the protoplasm, are pushed in between the molecules of the cell wall; it is thus enlarged to meet the requirements of its growing contents. Various considerations, such as the structure of the cell wall, its action on polarized light, and other peculiarities, lead to the conclusion that the liquid which thus carries each particle of cellulose to its appointed place is water, holding within it solid molecules of definite form, which are held apart by their watery envelope. A "water of organization" is therefore as essential to growth as the "water of crystallization" is known to be in the regular aggregations of the mineral world.

Every cell wall large enough to admit of close

microscopic examination is found to consist of three separate series of laminations, cutting each other at angles like the three planes of cleavage in certain crystals. First there are concentric layers of cellulose, like the layers of an onion, the outer and innermost of which are comparatively dense, while the intermediate layers are alternately more or less watery; the other two systems of striations are vertical, and cut across each other. Sometimes, under the glass, one, and sometimes another, of these shows most conspicuously. The introduction of particles of cellulose between the molecules of the cell wall, or intussusception as it is called, does not take place equally on all sides. The form of the cell, in consequence, becomes greatly altered during its development.

The most perfect illustration of free cell development, where the guiding force is wholly internal, may be found in pollen grains [Fig. 3] and elaters [Fig. 4, *e. e.*]. The irregularities which show themselves in the pollen grains, as spines, papillæ, spiral bands, depressions, and all the infinite variety of ornamentation on the surface of these minute cells, are due to unequal growth in the thickness of the cell wall; the variety in external shape is due to lateral growth.

In the lower algæ and fungi (sea-weed and mushrooms), growth is a mere aggregation of similar cells, each of which is capable of performing for itself all

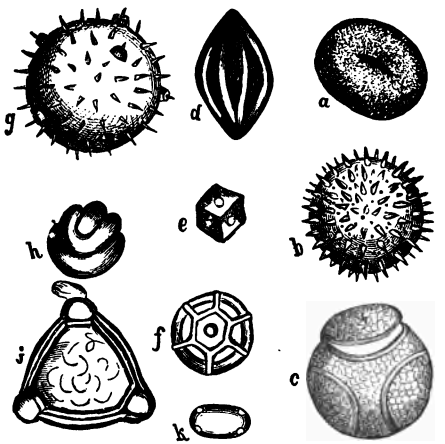


FIG. 3. POLLEN GRAINS.

g, Of *Cucurbito Pepo* [in water]; *d*, *Passiflora aquilegeæfolia*; *a*, *Pelargonium speciosa*; *h*, *Mimulus moschatus*; *e*, *Basella alba*; *b*, *Hibiscus trionum*; *i*, *Epilobium montanum*; *f*, *Chicorum intybus*; *k*, *Impatiens noli me tangere*; *c*, *Passiflora cærulea*. [After Henfrey.]

the functions of life. It is a sort of banding together of independent savages for the purpose of mutual protection and benefit. This being the case, each cell is capable of sustaining, without serious inconvenience, an independent existence; and in many instances we find them leading just such a life. In higher organisms there is a division of labor; each

cell has its function to perform for the whole, and it becomes modified, as it develops, with reference to its special work. The higher physical, as well as the higher social, life is characterized by mutual dependence.

The earliest forms of the higher organisms is almost identical with the permanent forms of the lower. A number of densely crowded cells, exactly alike, forms the rudiment of the plant; as these cells multiply there is a tendency to become definitely rounded on the outside; from the uniform cellular mass the surface layer becomes differentiated, the cell walls of these layers thicken and flatten, and we have an epidermis. Still further changes go on in the epidermal cells; some of the surface cells elongate immensely and form trichomes or vegetable hairs [Fig. 6]. The downy appearance of many leaves and the velvety softness of certain petals are due to the presence in vast numbers, of these trichomes. [See Fig. 7.] The forms of these minute vegetable hairs are sometimes very beautiful. In the plate, the stellate hairs of a leaf of Elæagnus is shown *in situ*, the vein of the leaf running across the middle of the plate. The forms are too numerous for description, but a variety may be

seen in Fig. 6. The prickles upon leaves are merely trichomes lignified; thorns proper do not belong to the epidermal system.

Throughout the whole plant, between the cells of which its substance is composed, are intercellular air-passages, which communicate with each other. The root end of all these passages is closed, but the upper end of each ramification opens into a larger air-space just below the epidermis. A surface cell above the air-chamber divides itself into two or more cells by running up double vertical walls. These walls finally separate, and the single epidermal cell is divided into two or more "guard cells of the stomata," as they are called. [See Fig. 5.] These guard cells are so constructed that in dry weather they close, and so prevent the escape of an undue amount of moisture, while in moist weather they open. The stomata form the million little mouths by which the plant inhales and exhales the atmospheric gases necessary to its life; and they also serve as pores for the exhalation of moisture. [See Fig. 5.]

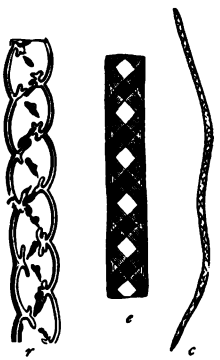


FIG. 4. ELATERS AND ROOT-HAIRS OF M. POLYMORPHA.

The only modifications of cells yet mentioned are those of the epidermal layers. While these are going on, changes quite as great are taking place within the cellular mass. String-like arrangements are formed, constituting strengthening tissue, which are called fibrous, vascular, or fibro-vascular bundles. Even the fundamental tissue between becomes somewhat modified. In this way there arises, by growth in all but the lower organisms, — not simply layers of uniform cells, but systems of tissue, unlike both physically and physiologically. This may be very clearly seen in Fig. 8.

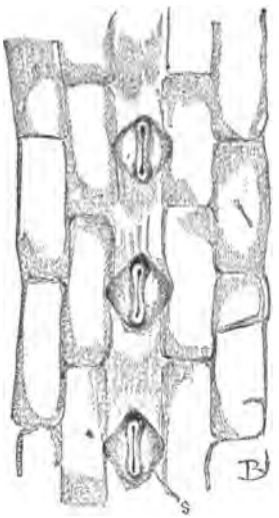


FIG. 5. STOMATA OF CORN-LEAF.

The fibro-vascular bundles become still further differentiated; the rows of cells lying lengthwise in the stem thicken externally while the walls which divide them are absorbed; and, as a result the row of cells is transformed into a single slender tube. [See Fig. 9.] These vessels, as well as the intercel-

lular air-passages, serve to convey air throughout the tissues of the plant. When the sap is rising they are sometimes found filled with it; but generally they contain only air; they are the lungs of the plant. The surface of these scalariform, spiral, or

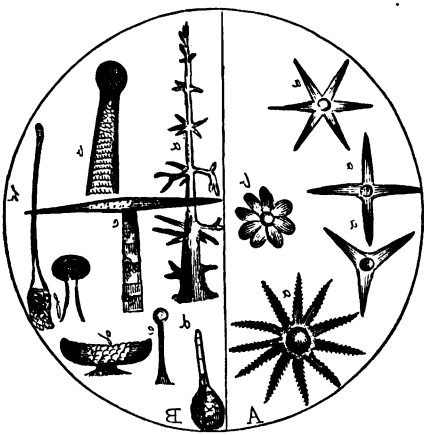


FIG. 6. GLANDS AND STELLATE HAIRS.

a a a a, Stellate hairs from *Deutzia gracilis*; *b*, hair from *Dioneæ* (from Nature); *c*, of *Alternanthera axellaris*; *d*, seta of rose; *e*, Sting of *Urtica urens*; *f*, from *Bryonia alba*; *g*, gland of hop; *h*, hair of chrysanthemum; *k*, from bulbil of *Achimenes*; *l*, gland of *Dictamnus fraxinella*. [After Henfrey.]

pitted vessels, as they are severally called, is most exquisitely marked with patterns of an almost infinite variety.

The lactiferous vessels are, like the spiral vessels, long rows of cells whose septa have been absorbed; these vessels convey from one part of the plant to

another certain dissolved material requisite for its growth. The intercellular spaces are also subservient to the same purpose. The cells pour out their juices into an intercellular space, and they are then conveyed away by the open channels lying between

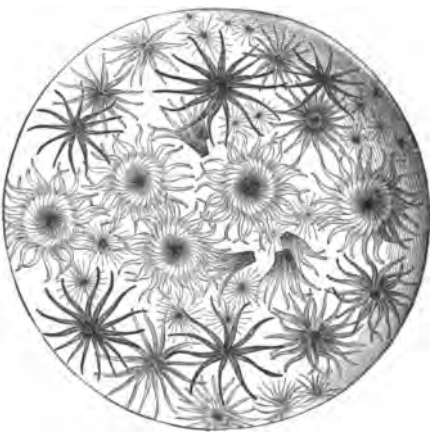


FIG. 7. STELLATE HAIRS FROM LEAF OF ELÆAGNUS IN SITU.
A, Hairs of midrib. [From Nature.]

the cells. A gland [Fig. 6, B, *d*, *e*, *g*, *h*] differs from these latex vessels in being a part of no lactiferous system, they are local formations, which, when they are upon the surface layers, often discharge their secretions outwardly. The sap-conducting passages are intercellular spaces, usually arising from the separation of adjacent cells; both sap and resin passages lie generally in straight lines, or fol-

low the fibro-vascular bundles. They resemble the lactiferous vessels in that they form continuous systems running through the whole plant. When they occur in the parenchyma, or fundamental cell tissue, they are generally distributed at nearly equal distances, forming a circle in the transverse section of the stem. [See Fig. 8.]

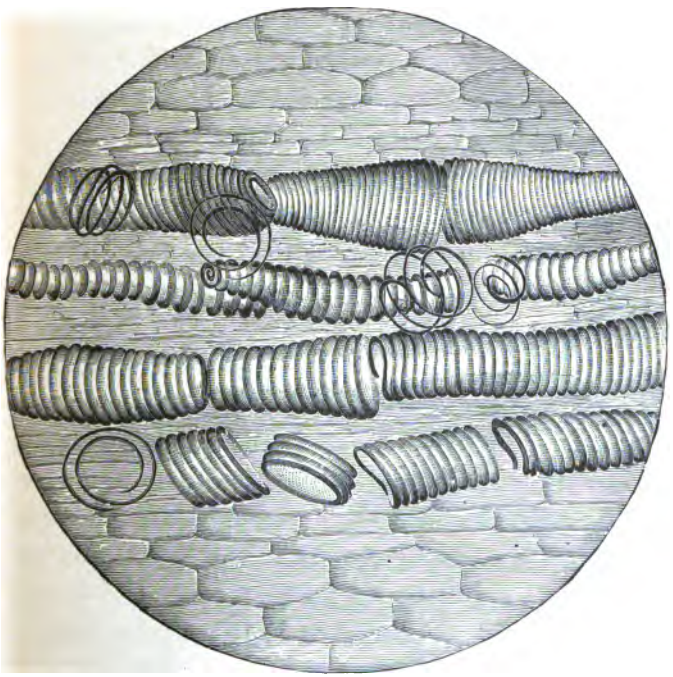


FIG. 8. SPIRAL VESSELS IN LEAF OF IMPATIENS BALSAMINA.
Touch-me-not, or Lady-slipper. [From Nature.]

The whole epidermal system is covered and protected by a continuous cuticle which also lines the vertical walls of the stomata. This cuticle, in its turn, is further protected by a delicate coating of wax, the "bloom" so familiar to every one. Sometimes it forms a continuous coating; at others it stands as a multitude of upright or curved rods; again it appears in the form of scales, or of a thick incrustation, giving evidence of laminations like the cell walls, or of layers of granules, or even as erect, doubly refractive four-sided prisms.

We have glanced briefly at cell modification and development, and considered some of its physical peculiarities; but we have not even looked into its life-history, or the functions performed by it, for the organism of which it is a part. The entire life of the plant depends on the action of light upon the cells, which contain chlorophyll. New organic compounds are formed only in these cells, and only under the influence of light. After a certain amount of assimilated material is stored up under the influence of the sun's rays, vegetative processes may, it is true, go on at their expense independent of the sunlight. This is especially true of seeds and tubers, which possess large stores of assimilated material.

But in the darkness the plant hybernates, rather than lives in the full sense of the word.

The whole animal kingdom may be said to depend upon the vegetable, in two senses. The atmospheric equilibrium is maintained by their mutual action. Animals consuming oxygen and yielding up carbonic acid (carbon anhydride), and plants consuming carbon and liberating oxygen; in this sense the two kingdoms are mutually dependent, though not equally so; but in another sense animal life is entirely dependent upon vegetable. In the tiny cellulose sac, by the vegetable protoplasm is wrought the very alchemy of life. There alone the inorganic elements of earth, and air, and water are transformed into the only material capable of sustaining animal existence.

Late investigations into the processes of vegetable life go to show that plants, like animals, inhale and consume oxygen, and exhale carbon anhydride; but this process, which is continuous and gentle, is masked by a much more vigorous action, which takes place within the chlorophyll particles under the controlling power of light. While the regular breathing of the plant goes on, consuming and liberating the same elements as the respiration

of animals consumes and liberates, the chlorophyll particles perform a work somewhat akin to assimilation. The carbon anhydride of the air is seized upon by them, the elements are separated, the carbon is consumed, and the oxygen associated with it is liberated. The quantity of oxygen thus freed, and of carbonic acid thus disappearing, so greatly exceeds any effects which during the day the reverse process of breathing could produce, that the gentle exhalation has been entirely overlooked. The store of oxygen has been found to increase steadily in air removed from all influences but those of vegetation. The chlorophyll particles also store up the formed material: the formation of starch, oil, and sugar seems to be a function of chlorophyll exposed to light, and their absorption a function of chlorophyll in the dark.

Nothing is more familiarly known than that sunlight after passing through a three-sided prism is spread out into an almost infinite number of rays, whose colors fade gradually into one another. These seven colors, as for convenience they are called, do not constitute the whole solar spectrum; for beyond the red end there is an invisible heat spectrum, and beyond the violet an invisible actinic spectrum.

The chemical decomposition of inorganic matter by light is effected by these actinic rays. A photo-

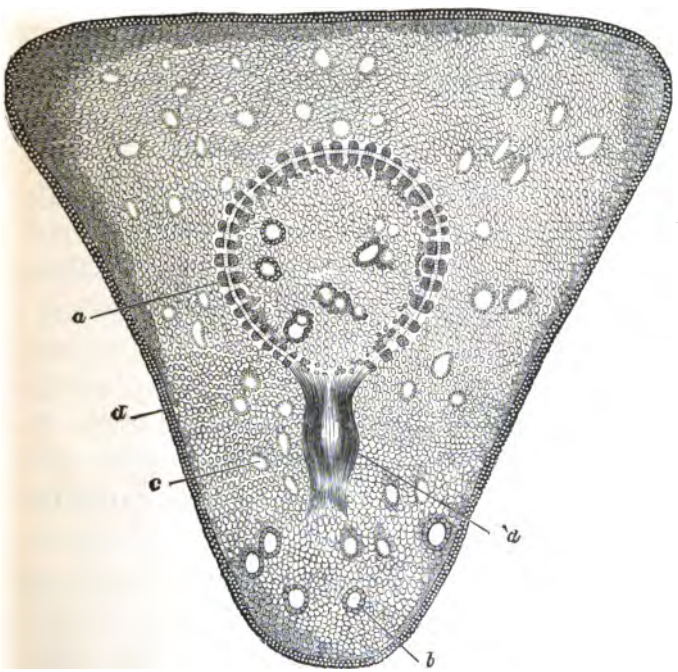


FIG. 9. CROSS-SECTION OF CACTUS STEM.

a, Fibro-vascular bundles; *d*, epidermal cells; *d*, vascular bundles in the direction from which a stem is about to be developed; *c*, intercellular spaces, with no separate cell wall. [From Nature.]

graph, for instance, may be taken in the blackest darkness, if only the ray of light be shorn of its

visible vibrations by being passed through some chemical which is actinically transparent. Experiments upon this point led physicists, very naturally, to divide the spectrum into three parts, which they called respectively, heat, light, and actinic spectra, the last being chemically active. Organic action shows this distinction to be false, for within our little chlorophyll bodies all chemical changes are wrought by the very rays, the red and ultra-red, which had been pronounced impotent. By these red and heat rays the chlorophyll is itself formed; the carbonic acid is separated into carbon and oxygen; the sugar, oil, and starch are produced. The mechanical processes of growth, of protoplasmic circulation in the cells, and the direction and movement of motile spores, are effected under the controlling influence of the violet and ultra-violet rays. All the solar vibrations which go to make up white light, therefore, appear to possess chemical power, though the matter affected by the several sets of rays is not the same.

The assimilatory cells [see Fig. 2 *a*], though the most important members of the society of cells, are not the only ones, by any means, essential to the welfare of the body corporate. Certain cells

which lie at the extremities of roots and branches, or at the base of leaves, are entirely devoted to the work of development and growth; these tiny cells seem to have discovered the fountain of perpetual youth, and to have tasted its magic waters—for they never grow old. They are rich in protoplasm, chlorophyll bodies, and cell sap, and they constantly reproduce themselves by various modes. In the first place, the protoplasm becomes rearranged around a new centre, the material being already present. The new protoplasmic body, which possessed a centre or nucleus, soon clothes itself with a cell wall. This process is the only one common to all cell formation. The development of the new cell and its separation from the parent may be effected in one of several ways. By *rejuvenescence*, or the formation of one new cell out of the protoplasm of the old one. By *conjugation*, or the union of the protoplasm of two cells to form one new one. By *multiplication*, or the formation of two or more cells by a division of the old protoplasmic body. This last mode may be effected in a number of ways: either the protoplasm gives off a new cell, still maintaining its own existence, or, the nucleus having previously dissolved, and new nuclei having

formed, it divides into a number of new cells. The first of these methods is called free cell formation, and is best illustrated by pollen grains, spores, and elaters; the second is called division, and is the general mode of reproduction in all tissue. The direction in which the cells divide determines the kind of tissue; a stem, for instance, is the result of longitudinal, while a leaf or a petal is the result of lateral, division.

Foreign and remote as this life seems to us, yet as we study organic nature more and more closely, the more startling do the resemblances seem. A casual glance, or even a close study, if it takes cognizance only of external and palpable facts, fails to find the bond which unites the sluggish existence devoid of sensibility which we find in vegetation, with the hopes and fears, the delights and anguish of our human lives. And yet, upon the physical side, such a bond does exist. Many things are common to all purely animal life, and it is hard to find anywhere a deep chasm which separates our race from the myriad forms of life beneath, if we ignore man's spiritual nature. Why should we fight about mere matters of anatomy, when we have a Plato, a Shakespeare, a Newton to point to? On the physical

side, man is undoubtedly allied to brute nature, as he is on the spiritual side to the Divine.

"I confess," says Sydney Smith, "I feel myself so much at ease about the superiority of mankind; I have such a marked and decided contempt for the understanding of every baboon I have ever seen; I feel so sure that the blue ape without a tail will never rival us in poetry, painting, and music, that I see no reason whatever, that justice may not be done to the few fragments of soul and tatters of understanding that they may really possess." This, to be sure, is not logic, but it is that witty common-sense which is the most powerful weapon ever raised to demolish false reasoning, and it is often of more value than much logic.

CHAPTER II.

THE SINGLE-CELLED GREEN PLANTS.

PLANTS as well as animals are classified according to their several modes of reproduction and nutrition. Modern botany does not satisfy itself with mere examinations of the forms of plants—it studies their development through their whole life history; such study has made plain the fact that there is a marvellous coherence in the plan of creation, that forms allied to each other in one way are apt to be found akin in others. It is, however, the interior life which determines relationship, and not mere external resemblance. The larger features of the old classification still remain characteristic of the new, though many organisms have changed places. It would seem to a mere casual observer to be arranged according to caprice, rather than by orderly adherence to the law of nature.

According to this classification, the algæ, fungi, and lichens are included in the group *Thallophytes*,

so called, because when they have any vegetative structure, it is leaf-like in form and character.

Many of the simplest of these plants have no vegetative body whatever. The entire organism is a single vegetable cell, which lives a complete and individual life, performing, on its own behalf, all the vital functions, and dying without ever having been associated with its fellows.

This simplest form of life is the lowest term of more than one ascending series; the highest terms of which are reached by several different ways. While one series represents this development by a gradation of forms, each one of which shows a more perfect differentiation of cells than the form which preceded it; another series shows it by the more and more complicated mode in which the cells are combined; and again another by the increasing delicacy and beauty of their external structure. In most cases, however, it is by a combination of these conditions that the transition is effected.

The lowest forms of life among the algæ are scarcely any thing more than a cell wall, containing a mass of colored protoplasm, in which a vacuole is always to be seen. Higher forms of single-celled plants show the protoplasm to be further differenti-

ated into colorless and colored portions, which contain granular materials, chiefly starch. A nucleus not present in the lowest forms now makes its appearance. The chlorophyll, or green coloring-matter of the cell, occasionally takes the shape of spiral bands, rings, or stars. [See Fig. 10.]

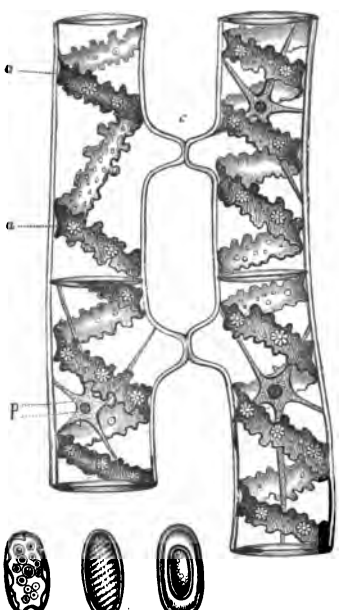


FIG. 10. SPYROGYRA LONGATA.
Same as Fig. 2, in Chapter I. [After Sachs.]

The ridges, dots spines and other surface ornamentations caused by the unequal thickening of the cell wall, which is so striking in pollen, elaters, and spores, is not very noticeable in the unicellular plants. The cell walls of these minute organisms show a tendency to turn into mucilage, which very materially aids in the reproduction processes.

Before proceeding further, it will be neces-

sary to describe briefly the phenomenon called Alternations of Generations,—a phenomenon rare and remarkable among animals, but very common in vegetable life. After a plant has grown a certain time, and its cells have come—by the process of differentiation described in Chapter I—to assume different forms and varied functions, by means of cell division, a time comes when single cells or special combinations of cells become detached from the parent organism, or cease to form a part of it. These portions of the plant have the power of producing new plants, like the parent from which they spring. Some of them are mere outgrowths of the vegetative structure, such as spores; others are so constituted that no further development can take place until a union with another reproductive cell is effected, the result of which is a seed. Among the simplest vegetable organisms, the reproduction by spores and like cells is most common; in the higher types the reproduction by seed prevails. Between these two are innumerable forms of life which reproduce, sometimes from spores or asexually, and sometimes from seed or sexually. When this is the case, and the two methods of propagation succeed each other, the phenomenon is called alternation of generations.

The plant and the reproductive body which it finally produces, are together called a generation; that which produces a spore is called an asexual, that which produces a seed, a sexual, generation; the terms spore and seed are used popularly, not scientifically, but these are fair types, and are familiarly known ones, of the two kinds of reproductive bodies. Botanists give a great number of names to make minor distinctions.

The simplest way of arriving at a clear conception of the processes which go on in these minute organisms is to select some characteristic form and follow it through its life-history. The *Palmoglœa macrococca*, in spite of its high-sounding name, proves to be, on closer acquaintance, only the common green slime which spreads itself over moist stones and walls, in secluded spots. This slime, under the microscope, shows itself to be a multitude of green cells surrounded by a sort of jelly. The cell wall, which is not very pronounced, is filled with greenish granules, among which may sometimes be detected a nucleus. [See Fig. 11, P, *b*, *c*.] Some among the cells in the microscopic field are seen to be elongated and constricted into an hour-glass shape in the middle; they are, in fact, undergoing the curious process

of multiplication by division; a process not precisely mathematical, but which, nevertheless, finds great favor in the vegetable world. Not only is it the cell,

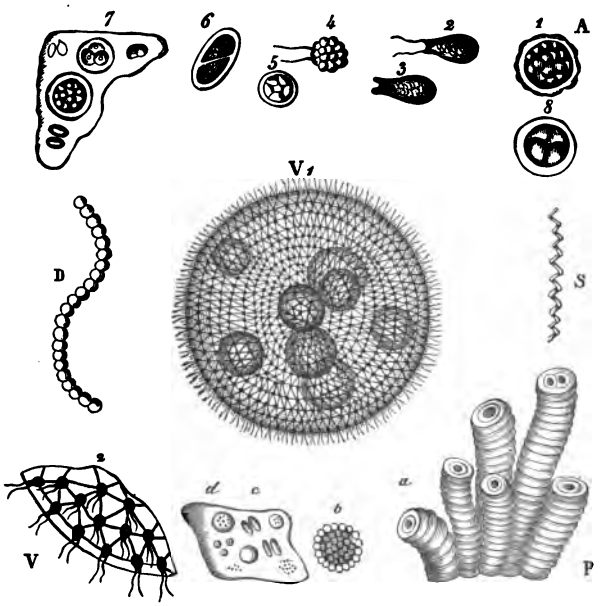


FIG. 11. A. PROTOCOCCUS PLUVIALIS.

1, Still form; 2, motile form; 1—8, different stages; P, *Palmogiæa macrococca*; *b*, *c*, ordinary conditions; *a*, urococcus; V1, *Volvox globator*; V2, portion still more magnified to show structure. [After Carpenter and Henfrey.]

which elongates, is constricted, and finally divides into two,—but the nucleus, very clearly to be seen

after the cell has been treated with iodine, also divides. The multiplication of cells goes on so rapidly that although each cell is probably not more than $\frac{1}{1000}$ of an inch in diameter, large areas are quickly covered with a coating of the palmoglœa. This process is merely one of growth similar to that by which higher organisms increase in size; except that here the cells are all alike, while in the higher plants the cells become to a greater or less degree differentiated, and thus the organs are produced which are fitted to fulfil special functions in the economy of the plant.

Alternation of generations has been detected even in this lowly life; we have already considered the asexual generation by division; the sexual form is here so simple, that a study of it is well fitted to be the initiatory step in the investigation of that curious phenomenon in vegetable life. Two of the cells which are completely developed become fused together. The extreme delicacy of the cell wall may be inferred from the fact that in this process the cellulose envelope, no less than its protoplasmic contents, enters into the fusion. The result of this conjugation is a spore, and from it springs a new colony by the process of subdivision. It is curious

to observe the analogies which run through nature; showing how essentially the purpose which underlies it all is at one with itself. During the conjugation of the palmoglœa cells, oil is produced within the spore in minute particles which coalesce and form drops,—on the other hand, when the spore begins to vegetate, producing new cells by subdivision, the oil disappears and the green granular matter takes its place. Just the same thing takes place in the higher plants; oil is stored up in the growing seed, and is consumed in its germination.

Let us now take a single drop of the greenish surface-water from some stagnant, way-side pool, and place it under the microscope. The green scum resolves itself, at once, into two single-celled forms [see Fig. 11, A, 1 and 2], the one oblong and motile, the other round and still. There are other forms of this little unicellular water-plant—the *Protococcus pluvialis*;—forms differing from each other so widely that they have been referred, not only to different species, but even to different genera; and under these protean disguises, have received no less than a dozen alarmingly long, and to the untrained tongue, unpronounceable, names.

It is only of late years that the tiny dwellers in

the earth, and air, and water, have been studied in their life-history; and this method of patiently following through each phase of its development these lowly forms of life, is the only one which can ever yield any knowledge worthy of the name. Such study, given to the protococcus, has shown that the dozen different forms, which in the old classification had received as many names, were but the changing shapes assumed by one tiny vegetable cell; it has also conclusively proved that it is vegetable in its nature, and not animal as had been previously believed. The distinction generally made by naturalists between the humblest representatives of the two kingdoms depends upon their powers of assimilation; vegetables possessing the power of transmuting inorganic into organic material, while animals require in almost every known instance organic food. This is true generally, though, like most other rules, it has its exceptions; since the experiments of Dallinger and Drysdale show that undoubted animal forms may exist in Cohn's nutritive fluid, which contains no organic matter. Studying the protococcus closely, it was found to possess the power of transmuting inorganic into organic material; this with other evidence has caused

it to be considered a vegetable form. The multiplication of the round, still cells takes place, as it does in palmoglœa; the cell contents and nucleus dividing into halves, and each of these undergoing a further division into halves and quarters. In this way, two, four, eight, sixteen, or more cells are formed, which are sometimes set free by the dissolution of the original cell wall, but are generally held together by its transformation into a gelatinous mass, in which they remain embedded. [Fig. 11, A, 7.]

Usually, when the still cells have divided into sixteen, but sometimes earlier, the new cells thus produced assume the motile form. [Fig. 11, 4.] A cellulose wall of some consistency forms about the new cells, tiny threads of protoplasm, called cilia (eyelashes), extend themselves through the envelope, and confer upon the organism the power of voluntary motion. They dart about over the field of vision, whipping the water with their tiny lashes so rapidly that the motion can only be detected by the currents they create. When they are about to come to rest, however, the motion slackens, and then the vibratile cilia may be seen with a good microscope and much patience. A slow evaporation

of the water in which the protococcus develops causes them to dry up, and they may remain for years in a state of dormant vitality. In this state they are wafted about in atmospheric currents, and are often brought down into cisterns and tanks by the rain-drops. There, finding favorable conditions, they vegetate and form a green superficial scum upon the water. The red snow of the Arctic regions owes its color to the presence of a red protococcus, or palmoglœa,—it is not quite certain which,—that multiplies with such rapidity that acres of ground are frequently covered in a single night. The urococcus [Fig. 11, P, *a*] is another form of the palmellaceæ, where some approach to higher life is made by the mode of union of the cells. Each new cell, which is of a delicate rose-color, is found resting in its cast-off investments, which finally form a pile of saucer-like gelatinous membranes, resting one within the other. Multiplication by subdivison gives rise to the several peduncles.

The transition is very easy from the motile protococcus living its hermit life, to the *Volvox globator* [Fig. 11, V], where precisely similar organisms are seen united together. The volvox is simply a well-regulated society of individual protococci,

where each member knows his place, and keeps it. The spherical body of the young volvox, as seen within the larger sphere, is at first composed of an aggregation of angular masses of protoplasm separated by the interposition of a transparent substance. The young volvox increases both by the growth of the protoplasmic masses and by that of the intervening hyaline substance. The masses of protoplasm send out processes which connect the different individuals into a compound body. V2, in Fig. 11, shows the mode in which the individual cells are united, as well as the appearance of the cells themselves. In the meantime the central mass of protoplasm shows one cell which is larger than any of the others; this is destined to become one of the interior spheres which develop along with the enclosing mass. As soon as the primary sphere has attained maturity it bursts, and the secondary spheres are free to follow the same course of development; volvox not only develops by division and growth, as just described, but also by a conjugation, or fertilization.

The *Volvox globator* is an inhabitant of freshwater pools, and sometimes reaches a diameter of one thirtieth of an inch. Its size is sufficent to

enable one to see it with the naked eye when the drop of water containing it is held up to the light. It usually moves by a kind of rolling motion; sometimes, however, it glides smoothly onward, and again it spins about its own axis like a top, without progressing at all. The motion is given to it by the rhythmic lashings of its thousand little cilia. It is seen under low powers to be a hollow sphere composed of a transparent substance, studded at regular intervals with tiny green spots, which are generally connected together by green threads. Within the sphere are the young volvox spheres of a still deeper green.

Among these simple organisms,—the confervoid algæ,—there are two forms of peculiar interest to the microscopist; they are interesting, not only for their intrinsic beauty, but also for the curious phenomenon which they present. These are the desmids [Fig. 12, B 1 and 2; E 1, 2, and 3; F] and the diatoms [Figs. 13, 14, 15, and 16]. The desmids, ranking lower than the diatoms, come earlier in our ascending series; there is, however, much which is very similar in their mode of development and life-history.

The *Desmidieæ* are a family of confervoid algæ

inhabiting fresh water; their outer coat is flexible, and is ornamented with minute markings which are

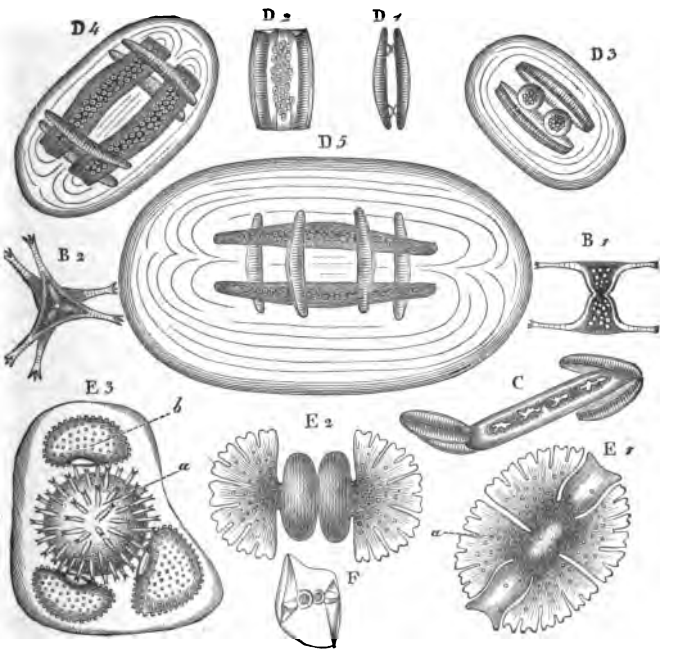


FIG. 12. DESMIDS AND DIATOMS.

Desmids, B 1, 2; E 1, 2, 3; F 1. Diatoms, C, D 1, 2, 3, 4, 5. Different stages of conjugation and formation of zygospore. [After Henfrey.]

always elevations. In a few of the higher forms, such as *Closterium* [Fig. 12, F], there seems to be a tendency, though not very marked, to secrete a

siliceous shell like that of the diatoms, though far less beautiful. The contents of the desmid envelope are like those of the other members of this class, a colored mass of protoplasm. The cells live isolated, and are symmetrically bisected by a deep constriction. [Fig. 12, E 1.] In each cell, Sachs tells us, there are two grains of starch and eight disks of chlorophyll. Where the desmid is about to reproduce itself by cell division, the neck which unites the two half cells [E 1, *a*] elongates, a double partition wall is run up through the middle of the connecting neck, the two portions become rounded [E 2], and finally each of the new-formed daughter-cells becomes exactly like the mother-cell from which it has developed, and we have two perfect desmids like E 1, joined end to end. While the neck is undergoing this increase, the two starch grains and eight chlorophyll disks elongate, become constricted, divide, and half of each passes over into the developing daughter-cell, where they arrange themselves symmetrically, as in the parent-cell. The two individual desmids finally break apart and lead independent lives. This is the asexual reproduction.

Conjugation shows some remarkable phenomena. Two cells lying in pairs in a crossed position emit a

thin jelly, in which they lie embedded; this investing jelly seems to be surrounded by a delicate gelatinous wall, and in this jelly is developed a new generation. The zygospore, as it is called, or new organism resulting from conjugation, takes a rounded form, or in some varieties divides itself into two as in F 1. In *Cosmarium* [E 3], it becomes invested by three layers of cell wall: an outer and inner transparent coat, and a middle layer firmer in texture, and brown. The outer cellulose layer develops upon its surface a number of spiny protuberances—at first hollow, afterward solid—which terminate in a toothed end. Alternate generation could scarcely be more strikingly exemplified than we here find it. The zygospore, sexual generation [Fig. 12, E 3, *a*], has no sort of resemblance to the asexual [E 3, *b*].

The germination or development of the zygospore into the desmid begins by the formation of a wide split in the outer spiny wall; through this the colorless inner layer, with its contents, protrudes, and finally escapes. The thin-walled sphere considerably exceeds the zygospore, from which it has just escaped, in size. In the protoplasm of the sphere may be seen two masses of chlorophyll. After a time, the contents of the sphere contract; it clothes

itself in a new cell wall, it becomes constricted in the middle, and finally divides into two half balls, each containing one of the two chlorophyll masses present before the division. The two half balls are enclosed in a spherical cellulose envelope, which after a time becomes absorbed, and the cells freed. All these processes of germination are completed within two days. The new cells, whose outer wall is smooth, begin to reproduce by division; the new daughter-cells, thus formed, are rougher and larger. The four daughter-cells produced from the zygospore are thus of two forms; the halves of two of these cells being unequal, while the two halves of the other cells are equal.

The diatoms, which have occupied so largely the attention of microscopic naturalists of late years, justify, by their exquisite beauty and enormous variety, the interest manifested in them. They resemble the desmids somewhat in the configuration of their cells, and in the manner of their division and conjugation, as well as in the tendency which they manifest to secrete a thin jelly, in which they live socially. What especially characterizes them is the beauty and variety of the siliceous shell which they secrete. Being of an indestructible material,

this delicate glassy coat has accumulated in geologic times to an enormous extent, and now forms vast layers in the strata of the earth's crusts. The city of Richmond, in Virginia, is built upon such a stratum, the extent and depth of which are not accurately known. A particle of this earth, dispersed over a microscopic slide so that it has a dusty appearance, reveals innumerable forms whose delicacy and beauty no drawing nor engraving can represent. The silica through which the ray of light passes in order to reach the eye disperses it, and the extreme beauty of the markings upon the shells is heightened by the delicate opalescent play of color which they show. The polycystina are minute animal cells which secrete siliceous shells, and are introduced here merely because they are so commonly associated with diatoms and were in this particular case mixed through them. [Fig. 13.]

The process of multiplication by subdivision may be seen [Fig. 14, C, *d*] in the *Biddulphia pulchella;* that by conjugation in [Fig. 12, 1, 2, 3, 4, and 5]; its successive stages of development, in the *Ennotia turgida.* These processes are so like those described in desmids that is not worth while to describe them in full.

The siliceous cell wall of a diatom is in two separate pieces, held together like the bottom and top of a pill-box, the older half being pushed down over

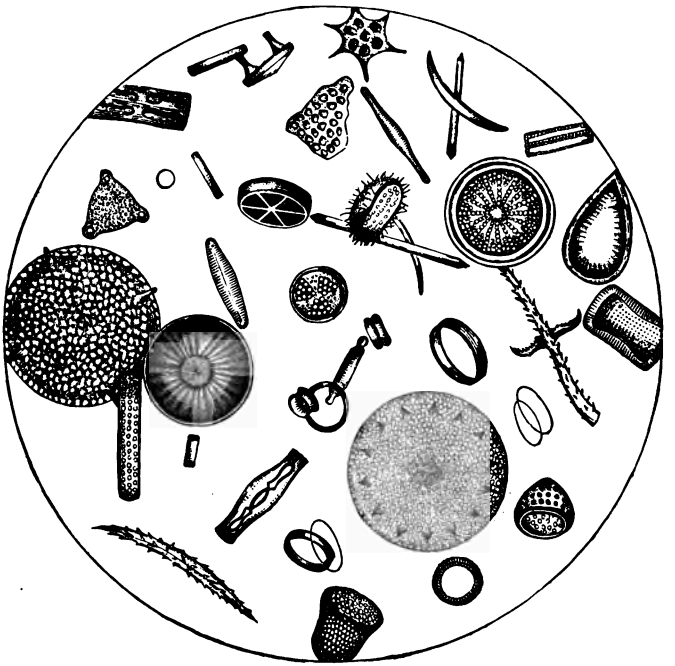


FIG. 13. COMMON FORMS OF DIATOMS AND POLYCYSTINA. 250 diams. [From Nature.]

the younger. When the cell is about to multiply by division, the middle band widens [see Fig. 14, C, *b*, and *d*], two daughter-cells form

within the extended bands; when they are complete the band in biddulphia seems to break, and each half to remain for a time attached to the cell. In all diatom slides these bands are present, having apparently fallen away from the organism after they had performed the functions for which they were designed [*e*]. The manner in which the upper valve fits down over the lower is questioned by some naturalists, but Sachs—one of the highest authorities on all botanical questions—states it as an ascertained fact, in the last edition of his "Text-book of Botany Morphological and Physiological," edited and annotated by Sidney H. Vines, 1882.

It is easy to see that if each newly formed valve occupies the position of bottom to the box, each cell becomes a shade smaller than the cell from which it was produced. In this way, when diatoms develop by division, they constantly deteriorate in size; according to Pfitzer, as quoted by Sachs, when the minimum size is attained, conjugation takes place, and the auxospore, or result of conjugation, is much larger than the diatoms from which it was produced; in this way a new series is begun with a diatom of the maximum size, which by division produces a series which, as regards mere dimensions, is a descending one.

Besides the ordinary rotation of protoplasm in their interior, both diatoms and desmids show a power of voluntary motion. They seem to be able

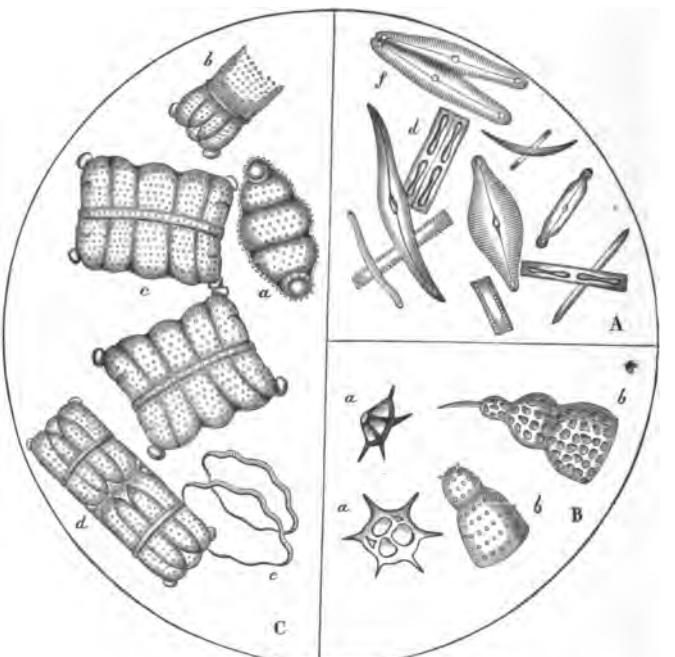


FIG. 14. DIATOMS AND POLYCYSTINA.

A, Various forms of Diatoms; B, Polycystina; C, *Biddulphia pulchella* (a diatom); *a*, top view of *B. pulchella*; *b*, half showing middle band widening in preparation for multiplication by division; *c*, two links in chain of diatoms; *d*, two completed individuals, still held together by middle band; *e*, middle bands broken away from *B. pulchella*. [From Nature.]

to creep about over hard surfaces, and to push small granules before them. This, in the diatoms, occurs

only in a line which extends along the length of the cell wall, and Schultze supposes "crevices, or holes, through which the protoplasm protrudes." Though such openings have never been actually seen, it is highly probable that they exist.

There is something approaching to social life among some species belonging to this family. Biddulphia and other varieties are found coherent by their alternate angles, and in this way form a sort of zigzag chain. Two links of such a chain may be seen in Fig. 14, C, *c*. In the *Chætoceros* the valves send out long tubular "awns" which look like ciliæ; these by their interlacing unite the individual cells into a filament. The frustules of licomorpha remain adherent after multiplication takes place, their form being wedge-like; a fan-shaped arrangement is the result [Fig. 16, A]. *Meridion circulare* develops in the same way, only to a greater extent, and the result is a radical arrangement which makes sometimes two complete circles spirally arranged. Bacillaria forms itself into long lines the sides of which are adherent [Fig. 16, C].

Many of the diatoms grow upon a stipes [stem]. Three varieties *in situ* are to be seen in Fig. 16, A, B, D. These present a distinctly plant-like appear-

ance, and have received the common name of brittle-worts. Such as are not fixed "by a stipes," Carpenter tells us, "possess some power of spon-

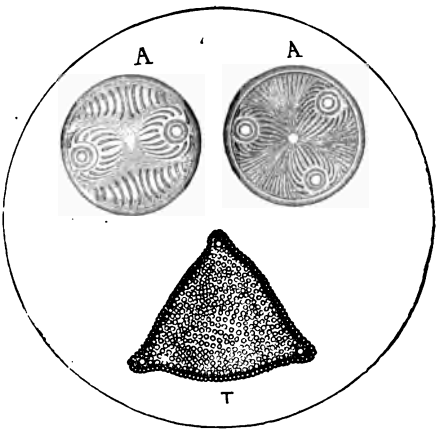


FIG. 15. DIATOMS.
A, A, two forms of Auliscus; T, *Triceratium*. [From Nature.]

taneous movement; and this is especially seen in those whose frustules are of a long narrow form. * * * The motion is of a peculiar kind, being usually a series of jerks which carry forward the frustule in the direction of its length, and then carry it back through nearly the same path. Sometimes, however, the motion is smooth and equable; and this is especially the case with the curious *Bacillaria paradoxa* [Fig. 16, *c*], whose frustules

slide over each other in one direction till they are all but detached, and then slide as far in the opposite direction, repeating this alternate movement at

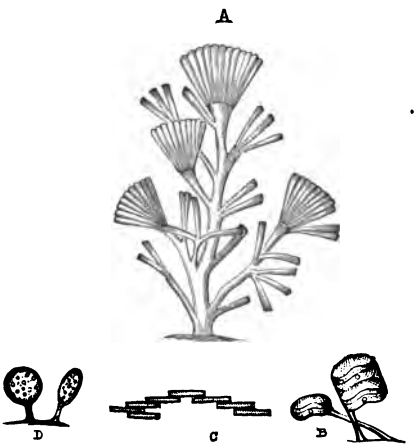


FIG. 16. DIATOMS GROWING ON STIPES.

A, Licomorpha; B, Achnanthes; C, Bacillaria; D, Pododiscus. [From Nature and after Henfrey and Carpenter.]

very regular intervals. In either case, the motion is obviously quite of a different nature from that of beings possessed of a power of self-direction. 'An obstacle in the path,' says Professor W. Smith, 'is not avoided but pushed aside; or, if it be sufficient to avert the onward course of the frustule, the latter is detained for a time equal to that which it would have occupied in its forward projection, and then

retires from the impediment as if it had accomplished its full course.' "

The observations recorded by Focke make it very probable that, when the family of diatoms shall have been studied more thoroughly and exhaustively, many forms which are now considered different varieties, or even different species, will be found to be merely the various stages in the development of a single variety. A writer in the "Annals and Magazine of Natural History" states that he has found two or more distinct species upon the same stipes, which makes the probability even greater.

There are others among the confervoid algæ which are, in one sense, unicellular plants, and which yet assume forms that are distinctly plant-like. Though each cell lives only for itself, yet they always live in union. The *Spirogyra longata* [Fig. 10] is one of these organisms. Though it belongs to the *Conjugateæ* yet in its mode of sexual multiplication the reproductive process of higher organisms is shadowed forth; and it seems to furnish the connecting link—the transitional form—between the conjugating and the fertilizing mode of reproduction.

Every filament consists of a row of cylindrical

cells, each containing a protoplasm sac, which encloses a large proportion of cell sap. A nucleus [Fig. 10], hangs suspended in a small mass of protoplasm, which sustains itself by attaching threads extended to the cell wall. The chlorophyll is arranged within the sac of protoplasm in the form of a spiral band, studded with flower-like aggregations of starch grains. The figure represents the filaments preparing to conjugate. A protrusion is sent out from the two adjacent cell walls of parallel filaments; these grow until they meet. The protoplasm sac of each of the two cells first contracts; it then detaches itself completely from the surrounding cellulose envelope, rounds itself to an ovoid form [Fig. 10], and contracts still further by the expulsion of cell sap. After this process is completed in both cells, the wall between the two protrusions opens, and one of the ovoid bodies forces itself through the passage thus formed; the moment the two masses of protoplasm meet, they coalesce. When the union is complete, the two masses are formed into one, hardly larger than either of the coalescing bodies, and of the same ovoid form.

The union gives the impression to the eye of the

union of two drops of liquid; but that it is utterly different is clearly proved by the fact that the two spiral bands of chlorophyll place themselves end to end, making one continuous band coiled more closely than before. The conjugated body clothes itself with a cell wall, and becomes what is called a zygospore; after some months of rest, this germinates, producing a new filament of cells.

The step toward a higher mode of reproduction taken by the spirogyra may be seen by comparing its mode of conjugation with that of the strictly unicellular plants. Protococcus, palmoglœa, desmids, and diatoms, either fuse, and both cells form a new one; or else they expel their cell contents and the reproductive cell is formed outside both the original cells; but here in the conjugation of the filaments of spirogyra, though no chemical or physical difference can be detected in the conjugating cells, one filament sends all its protoplastic masses over into the other, and remains itself, emptied of its cell contents,—the other filament giving rise, in each of its conjugating cells, to zygospores. There must be some difference between the two filaments, though it is so subtle as to elude the most delicate chemical and microscopical tests

which have been so far applied to the solution of the question.

In the close study of life, in its narrowest and lowest, as well as in its broadest and highest manifestation, we are always brought to a point where the mystery is as impenetrable as though the Divine fiat had gone forth, "Thus far shalt thou go and no farther." There is no scientific answer to the question that presents itself. Science has penetrated into the mysteries so long baffling the world, how this wonderful work is accomplished, what are its modes and processes; but science is no less dumb than is ignorance when the question comes, What is this mysterious life-power, this wonderful, underlying, vital force? There *is* a solution offered,—the only solution which does not refute itself,—a solution too simple, perhaps, for those who are bent upon looking back through millions of ages to the fiery gas out of which, they say, not only our worlds and systems of worlds have been developed, but out of which every gigantic intellect and every loving heart have been evolved. St. John gives a hint of this answer when he says, "In Him [the Divine logos] was *life*, and the life was the *light* of men." It would seem from this that the mysterious

power which constitutes life, whatever that may be, was the breath of God breathed into every living creature; while to man this Divine presence means more than merely physical vitality and that limited power of loving and thinking which belong to the brute creation. It means, to man, the power to "look before and after," to recognize the subtle relation between the material and spiritual. It is to him that gift of spiritual vision which enables him to respond to the thoughts, the commands, the infinite love of God.

CHAPTER III.

FUNGI AND LICHENS.

MANY of the fungi are single-celled plants, and belong to the same class with the microscopic algæ of the last chapter. They differ radically, however, in one point from the protococcus and all other green plants, for they are entirely destitute of chlorophyll. They are cellular, flowerless plants which must for their food have matter which has once, at least, passed through the phase of vegetable life. Some of them, like mushrooms, live in earth rich in the remains of leaves and other dead matter; others are parasites upon living organisms, plants, and animals: but all alike are wanting in that wonderful substance chlorophyll, which enables the green plants to get from the earth, the air, and the water, mineral substances, and to convert them into its own tissues.

We are apt to think of the fungi as very unimportant members of the vegetable kingdom: the humble mushrooms and toadstools make up the class in

the estimation of most people. These are, it is true, the most conspicuous members of the fraternity, but they are of comparatively little consequence in the economy of nature, particularly in America, where the esculent fungi are held in small estimation. The really important fungus plants are either microscopic, or else so small as to attract little attention. To the microscopist, fungus life seems omnipresent ; the germs of these tiny plants fill the air we breathe, are present in the food and the water we consume, and form an integral part of the dust beneath our feet. Almost every substance in organic nature offers a field ready for their growth, the only conditions necessary being warmth and moisture. All the mildew, the mould, the fermentation, the decay that are going on in the world is due to their presence. They are the little imps of mischief in the natural world, which are always lying in wait to play their pranks and work their spells of evil. Blighted crops, desolated vineyards, pestilence among the silk-worms of France, and the cattle of Russia, are alike due to the success of their machinations.

In studying these forms which touch human life at every point, the most beneficent of scientific

discoveries have been made, and an illimitable territory remains yet to be conquered. It may be in our time that malaria and miasma, with all the pestilences following in their train, will have been tracked to their source—as splenic fever has been followed,—and that the very organisms which cause them may be found and watched through all the stages of their development; the conditions of their life determined, and the mode of dealing with them ascertained. After the work of Pasteur, in France, on the grape fungus, the silk-worm fungus, the beer fungus, what may we not hope, now that that keen and subtle intelligence is directed toward the yellow-fever pestilence and kindred diseases?

The work of the invisible fungi are not all for evil: like fire, they are very good servants and very bad masters. These same little organisms which are so powerful for evil, are powerful for good too, if carefully placed and intelligently directed. The bread which makes our every-day food, the wine, and beer, and vinegar, on our tables, are all due to their orderly action, wisely directed and intelligently arrested.

A fungus may be considered as consisting of two distinct parts. The first of these is the vegetative structure or thallus. It has received the name, in

this group, of *mycelium*, and is composed of innumer-

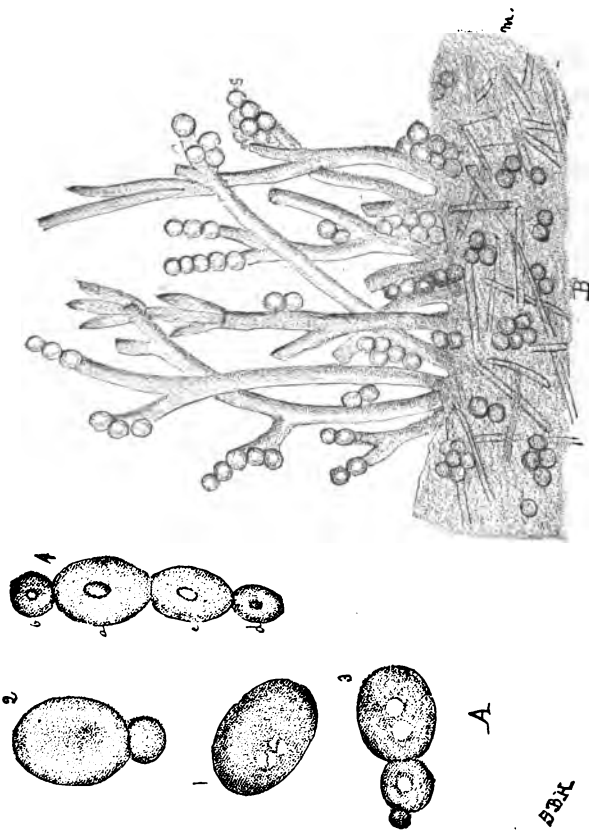


FIG. 17.

A, *Torula cerevisiæ*. 1, single; 2, 3, budding; 4, chain of cells. B, *Penicillium glaucum*. *s*, spores, or conidia; *m*, mycelium; *h*, hyphæ. [From Nature.]

able delicate, jointed filaments, which are interlaced and woven into a felted mass. Each filament is

colorless, and branched, and in the aggregate produces in vegetable structure, earth, etc., a white cottony mass, and in liquids cloudy flocks. There are certain modifications of this thallus, but nothing widely divergent from the typical form. It is the mycelium which forms the "spawn" used for planting mushroom beds, and which goes to make up the essential element of "mushroom bricks," which serve the same purpose. The second part of which a perfectly developed fungus may be considered as consisting, is the fructification; and this differs very greatly in the various tribes. In the simplest forms, the fructification is nothing more than a modification of the terminal cell of one of the aërial filaments springing from the mycelium.

One of the simplest, as well as the most characteristic, of the single-celled fungi, is the *Torula cerevisiæ*, or yeast plant. A drop of common baker's or brewer's yeast, examined under a power magnifying several hundred diameters, shows itself to consist of a fluid medium, in which quantities of minute spherical or oblong cells are suspended. If this drop be placed in a watch crystal and supplied with nutriment in the form of some fermentable fluid, rich in albuminous matter and sugar, these cells show themselves to be endowed with vitality. [Fig. 17, A.]

There are so few cases where plant growth can be watched, and its results chemically tested, that it will be worth while to follow the development of the torula-cell through the process of its growth and multiplication. In order to do this the cell should be placed in some nutritive medium: this in the case of bread is supplied by the flour and water; in beer by the wort; in wine by the juice of the fruit, or the sugar and fruit juice mixed. The growth and development of the plant produces in these different substances, fermentation, which causes the bread dough to rise; the wort and "must" to be changed into beer and wine.

That we may understand the organic and chemical changes which constitute fermentation, let us "plant" a small quantity of yeast in an appropriate nutritive fluid. The same process then takes place as makes our bread dough rise. Pasteur, the great French chemist, who has done more work and, it is probable, better work than any one else upon the causes of fermentation, has prepared a fluid which perfectly meets the needs of the growing *Torula*, and makes it possible to watch its development under the most favorable conditions.

A drop of yeast may be placed with a spoonful of

Pasteur's solution in a watch crystal and examined under a power of about four hundred diameters; the larger cells then look about one fifth of an inch long. After a time, close observation detects a growth among the smaller cells, which continues till they reach the maximum size, somewhere near one-three-thousandth of an inch. After this size is attained, no change is observed for a time; the little plant seems to be gathering up its forces for the act of vegetative reproduction. Further observation detects in a little while a new growth. From some point in the cell wall a minute projection appears, like a tiny bud; this becomes larger and larger, till a new cell, still attached to the parent form, is matured, and finally equals its progenitor in size. In about three or four hours, under favorable conditions, the new cell begins in its turn to bud, and a second generation is developed in just the same way as the first. So long as the fluid medium affords both sugar and nitrogen, this process continues; when either is exhausted, a new process begins. [Fig. 17, A 1.]

The cells of the *Torula*, when supplied with the free oxygen of the air, grow with great rapidity, absorbing oxygen and yielding up carbonic-acid gas.

This, it will be remembered, is the process of true respiration, common to all vegetable cells. It goes on continuously in the cells of the green plant day and night; but it is so completely masked by the more powerful process of assimilation effected by the chlorophyll under the influence of sunlight, as to escape observation during the day. The cells of fungi, as we have said, possessing no chlorophyll, lack this power, and with them the breathing process may be observed to go on in light and darkness alike. As a result of their respiration, carbonic acid is continuously exhaled, and oxygen continuously absorbed.

With the *Torula* and other fungi, the case stands thus: if confined under an air-tight bell-glass, the cells of the fungus would continually breathe in oxygen, and breathe out carbonic acid, till the limited supply was exhausted, and then perish; it is therefore forced to find some other means of making its living. So long as the *Torula* has plenty of good fresh air, scarcely any traces of fermentation are to be found; it is merely feeding upon the fluid, as green plants feed upon the nutriment they find in the soil. But when the cell is submerged it turns to the fluid medium not only for

its food, but for air,—for oxygen, which is the element in the air needed for the respiration of plants and animals alike. It forthwith decomposes the sugar in the solution (for all nutritive media have sugar in them) and appropriates the oxygen which is one of the elements of the sugar, liberating alcohol, which is another of its components. All fermented fruits or preserves give evidence of this; they all have an alcoholic flavor. Bread has not this taste, because the process of fermentation is arrested before much alcohol has been produced, and because, if properly baked, the fumes of the alcohol are dissipated by the heat. If allowed to "rise" too long, too much sugar has been abstracted from the flour and the bread is sour. "The act of fermentation, then, is," in the words of Tyndall, "a result of the effort of this little plant to maintain its respiration by the means of combined oxygen when its supply of free oxygen is cut off." As defined by Pasteur, *fermentation is life without air.* But it is a severely conditioned life, and "just here the knowledge of that thorough investigator (Pasteur) comes to our aid to warn us against errors that have been committed over and over again. It is not all yeast cells that can thus live without air and

provoke fermentation. They must be young cells, which have caught their vegetative vigor from contact with free oxygen. But once possessed of this vigor, the yeast may be transplanted into a saccharine infusion, absolutely purged of air, where it will continue to live at the expense of oxygen, carbon, and other constituents of the infusion. Under these new conditions, its life as *a plant* will be by no means so vigorous as when it had a supply of free oxygen, but its action *as a ferment* will be indefinitely greater."

Very closely connected with the *Torula* is the plant which turns the grape juice into wine. It is necessary, in order to make bread rise, or beer ferment, to plant the germs, but grape juice needs no such artificial aid to become wine. The juice of the grape, as it grows, is hermetically sealed in its skin, so that no germ-filled air can find access to it. And yet, if the expressed juice of the grape be protected from the air, it will ferment of itself. The reason of this is, that the germ of the plant, which had to be sowed in the wort, nature has supplied to the grape. Examined microscopically, the little fungus plant necessary to the proper fermentation of grape juice or "must" is found adherent to the stem and skin

of the grape. [Fig. 18, Grape Fungus.] By crushing the grape, the juices sealed up in the skin are

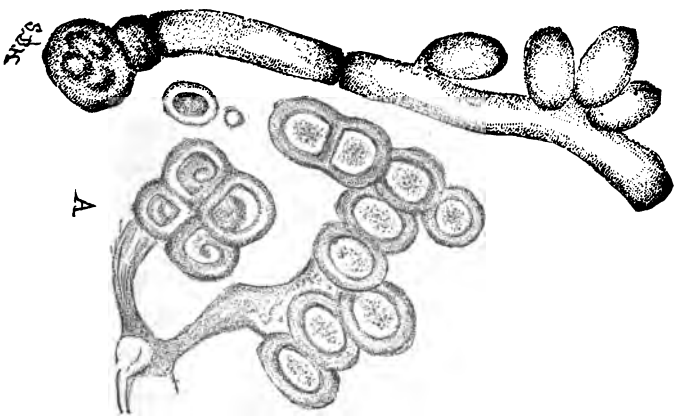


FIG. 18. GRAPE FUNGUS. (AFTER PASTEUR.)

brought into contact with the germ, and the process begins spontaneously.

The brewer finds a multitude of precaution necessary in his beer-making to prevent other germs than those he has planted taking root,—the noxious "weeds of this microscopic garden which often overshadow and choke the flowers." All uncertainty in brewing comes from the invasion into the wort of foreign organisms, which produce fermentation, it is true, but not of the desired kind.

The process of fermentation, which we are apt to

consider one of death and decomposition, is, on the contrary, always and only the result of life. Crushed fungus cells, though their chemical constituents remain absolutely unchanged, never produce it; it comes only in consequence of the vital process of living, growing plants.

Closely connected with fermentation is the familiar phenomenon of mould, which is also due to the presence of fungus vegetation. Let any ordinary article of vegetable food be exposed in a damp place to the access of air, the damper and darker the spot the better, and it will be found covered with a coating of one kind of mould or another. The commonest form which occurs upon bread, paste, jam, pickles, etc., is the *Penicillium glaucum.* This is a most beautiful object under a low microscopic power. From a matted and undistinguishable mass, composed of the mycelium and the substance in which it has developed, spring innumerable delicate glassy tubes, shining with a silvery lustre. The tubes branch out here and there, and the field is covered over with myriads of tiny, perfectly spherical cells of the same diameter as the tubes. These are the spores, which are formed by numerous constrictions taking place at definite intervals,

to some distance below the apex of the several filaments. When the constrictions are complete, the end of the filament looks like a necklace of silvery beads; these are very easily detached. When sowed in Pasteur's fluid, one of these little spores begins a vegetative life. In the course of a day or two the spore may be seen to be the centre of two or more radiating tubes. This is the beginning of a new mycelium, which will grow and fructify in its turn. (Fig. 17, B.)

Another common mould which occurs upon paste and decaying vegetable matters, is the *Mucor mucedo.* With the unassisted eye, the cobwebby consistence of the mould may be seen penetrated by upright stems bearing a globule on the end. When one of these is snipped off with a pair of sharp-pointed scissors, and placed under the microscope, it shows a more complicated fructification than *Torula.* The globe is at first a mere globular enlargement at the end of an individual tubular filament. Soon a horizontal wall or septum shuts off the globe from its stem. The contents of the globe develop into multitudes of spores, while the septum is pushed up in a very convex form into the midst of the spores, like the core of a mulberry, and is called the colu-

mella. The outer investment bursts when the spores are mature, and scatters them abroad.

The invariable appearance of fermentation, and of mould, whenever the conditions for its development are present, is not at all difficult to account for. By many different means it has been ascertained that the air we breathe is charged with innumerable floating motes. Tyndall tried the experiment of making these visible by projecting a cone of the brilliant electric light into a darkened room. The air where the light falls seems almost a solid, though light itself is invisible and can only be tracked by the presence of minute bodies from which it is reflected.

"The universality of the appearance of these simple forms of fungi upon all spots favorable to their development," says Dr. Carpenter, "has given rise to the belief that they are spontaneously produced by decaying substances; but there is no occasion for this mode of accounting for it, since the extraordinary means adopted by nature for the production and diffusion of the germs of these plants adequately suffices to explain the facts of the case. The number of sporules which any one fungus may produce is almost incalculable; a single individual

of the puff-ball tribe has been computed to send forth no fewer than ten millions, and their minuteness is such that they are scattered through the air in the condition of the finest possible dust, so that it is difficult to conceive of a place from which they should be excluded."

Not only are fermentation and mouldiness caused by the development of organic germs, but all putrefaction has the same origin. The oxygen of the air, which the older naturalists and physicists thought to be the cause of decay, has been proved entirely guiltless. The most delicate substances, such as milk, fresh meats, and fruits, can be kept indefinitely if they are cut off from the invasion of fungus germs. The whole rationale of refrigeration and canning for the preservation of such articles of food lies here. Ice serves for purposes of preservation, because germs can no more develop than other plants can grow in an excessively cold place; the *conditions* of fermentation are therefore not present: and in the case of canning, the steam from the heated mass excludes the air, and with it all suspended germs, so that the *cause* of the fermentation is absent.

The fungus plants which occasion putrefaction have received the name of Bacteria. These are found

in all decaying matter. Some years ago, desiring to secure some of these organisms, a watch glass was

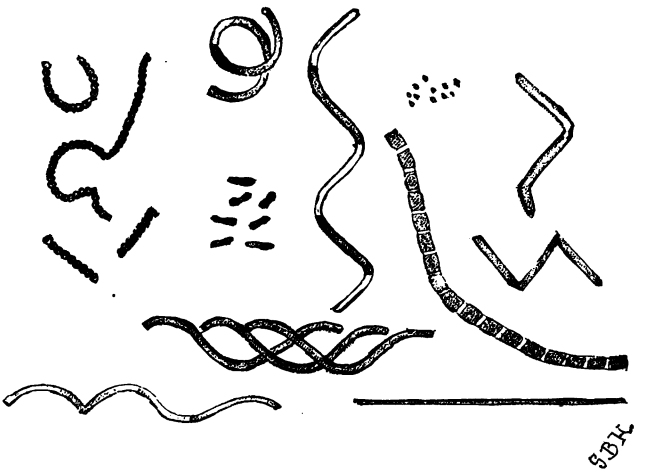


FIG. 19. BACTERIA. [FROM NATURE.]

dipped into a metal tank used for soaking bones before mounting some skeletons. The teaspoonful of water came up a little cloudy, and more than a little unsavory. These few drops, placed under the microscope, were full of Bacteria, moving over the field of vision. Straight, rod-like bodies of glassy texture, wavy transparent tubes, cork-screw spirals whose gyrations produce the effect upon the eye of wriggling; necklaces of beads, or single spheres

groupeo together with many other forms,—all living, moving, struggling, growing, and multiplying within the limits of a single drop of water. The uninitiated observer could not look into this little world of active life and doubt that he was viewing some phase of animal existence. Close observation of their mode of life and nutrition, long months of patient study and careful experiment, have, however, determined the fact of their vegetable nature. [Fig. 19.]

Mildew, which is so destructive to cotton and linen fabrics, is nothing but a minute fungus plant which finds its nutriment in the fibre of the material, and grows when it is left long enough undisturbed and supplied with moisture to give it a chance. [Fig. 20, A.]

What is true of these minute forms of fungus life is true of the more complicated; they live always at the expense of organized matter. If the matter be dead the result is, that certain elements are chemically abstracted, which destroys the equilibrium of the medium in which they are growing, and such destruction of chemical equilibrium we call in common language souring, fermentation, or decay, as the case may be. There are other fungus forms which grow at the expense of living matter, and the result of their growth is disease.

The potato disease is due to the presence of a fungus, the *Botrytis infestans*, which grows in tufts

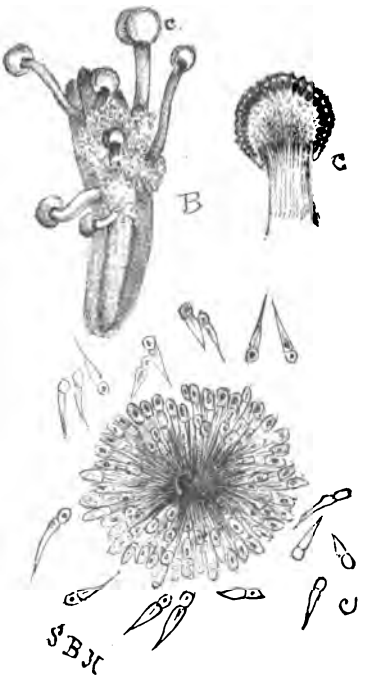


FIG. 20. MILDEW AND ERGOT.
A, Mildew. B, Rye smut or ergot. C, Section of head *c*.

on the lower surface of the leaves of the plant, and also on the surface of the tubers. It seems altogether probable that the fungus is usually present,

but that like other parasites it is unable to develop except upon the cut surface of a healthy potato. When, however, the plant loses its vigor in consequence of forcing, or from other causes, the sporules not only germinate on the surface, but they send out ramifying processes which penetrate the interior of the tuber. The mildew of wheat, the ergot of rye, and a thousand other common diseases of plants are due to the growth of one or another of the fungus family. [Fig. 20, B.]

One of the diseases to which the silkworm is subject, called *muscardine*, is also a fungus growth —*Botrytis vassiano*. The sporules which are floating in the air enter the stigmata or breathing-pores of the silkworm; these communicate with the tracheal or respiratory system of the larva. The sporule develops, penetrating the air-tubes till they are filled, then extending themselves through the fatty tissue just beneath the skin, appropriating the stored-up material necessary to the development of the pupa. The disease always causes the death of the worm attacked, but it does not make any external appearance till after this, when it shoots out from between the rings of the body. It is never known to attack the silkworm at any other

stage but the larval; but it may be communicated by inoculation to either the chrysalis or the mature insect. Since the nature of the disease was known, its spread has been greatly checked; diseased worms, instead of being left near the living colonies to fill the air with the ripened sporules, are now carried far away or destroyed.

A fungus parasite is found to infest the common house-fly, *Empusa musci*, which is not unlike the Botrytis in its mode of attack. The spores enter the spiracles or stigmata; the mycelium penetrates finally the whole body of the insect, while the fructification stands out from the skin like the pile of velvet, and the spores thrown off from the filament make a whitish ring about the infested fly as it stands miserably glued upon the window-pane.

The diseases in the vegetable world exercise a tremendous power over human life, though they do not touch it so closely as do the diseases to which animal life is subjected from the same cause. The vessels of the living body, whether of man or animals, are sealed up beyond the reach of putrefactive germs so long as they are in a sound and healthy state, as effectually as the grape is sealed against the germs of fermentation; and entrance is sometimes

effected in the same way, by an abrasion of the cuticle. Of late years, since the microscope has been turned to every curious point in pathology, it is found that the exciting cause of inflammation and suppuration in wounds is the presence of Bacteria.

"Take the extracted juice of beef or mutton," Tyndall says, "so prepared as to be perfectly transparent, and entirely free from the living germs of Bacteria. Into the clear fluid let fall the tiniest drop of liquid charged with the Bacteria of putrefaction. Twenty-four hours subsequently the clear extract will be found muddy throughout, the turbidity being due to swarms of Bacteria generated by the drop with which the infusion was inoculated. At the same time the infusion will have passed from a state of sweetness to a state of putridity. Let a drop similar to that which has produced this effect, fall into an open wound; the juices of the living body nourish the Bacteria, as the beef or mutton juice nourished them, and you have putrefaction produced within the system. The air, as I have said, is laden with floating matter, which, when it falls upon the wound, acts substantially like the drop." The aim of the most advanced practitioners

of modern surgery is to prevent the access of these bacterial germs, or to destroy them after they have invaded the tissues. The earlier practice attempted to effect the exclusion of these germs; the later finds their destruction the most effectual means for preventing the evils due to their presence.

The method used by Prof. Lister, who successfully practised the second means,—that is, destroying bacterial germs,—was to shower upon a wound, during the time of dressing, the spray of some liquid capable of killing the germs. Dilute carbolic acid, in various combinations, is the commonest liquid used.

The whole course of splenic fever, which is caused by the presence of Bacteria in the blood, has been carefully studied by a young German physician, the cause of the contagion in the presence of the spores discovered, and the prevention of contagion made possible. The common name for this disease in human beings is malignant pustule. Diphtheria, the awful disease which every year sweeps off its thousands; blood-poisoning in many of its forms, and hundreds of other diseases, have yet to be studied fully, but are probably due to the presence of some form of fungus in

the blood or mucous membranes of the body. To know the cause of those diseases, is to give a hope of some final method of cure. At least, the experimenter knows where to direct his efforts; knowing the cause, there is hope that some mode of prevenion may be found, or some method of cure.

In America, and even in England, little attention is paid to the value that certain kinds of fungus growths have as articles of food; mushrooms and truffles are rare delicacies with the Anglo Saxon peoples. The Latin peoples have learned to value these articles of diet as nutritious food, their very laziness and poverty having induced perilous experiments as to their value. In England, upward of thirty esculent mushrooms are found, though they are not generally used. In France, Germany, and Italy, thousands of people live upon them for weeks at a time. As long ago as 1847, fresh fungi which were sold in larger quantities than ten pounds showed a yearly consumption of about 70,000 pounds in the city of Rome alone. Adding to these the small lots brought to market (which were not taxable, and of which there is, therefore, no official record), those eaten by the poorer classes who gathered them, those dried, preserved in vari-

ous ways, and pickled, the amount given may be multiplied by four, and then fall well within the facts.

This apparently insignificant class of plants,—edible and non-edible fungi—include thousands of species; they are everywhere like vegetable leeches which "stick to the bulbs of plants and suck them dry." A wonderful story is told of a cask of wine which was put away in an unused cellar to ripen, by Sir Joseph Banks. At the expiration of three years, he directed his servant to ascertain the state of the wine. The door of the cellar was so tightly shut that it had to be hewn down. Then the cellar was found filled with a fungus growth, the wine was all gone, and the empty cask had been carried up to the ceiling by the growing fungus. This is given on the authority of *Chambers's Journal*, and quoted in Badham's "Esculent Fungi of Great Britain."

The growth of these large fungi is marvellously rapid. *Phajus impudicus*, a long horn-like excrescence of great beauty, but which has an insupportable odor, expands so rapidly and with such force that it will sometimes shiver a glass vessel in which it is enclosed, with a loud report. A paving stone weighing eighty-three pounds has been lifted for the

distance of one and a half inches above the ground by the growth of a cluster of Agarics.

FIG. 21. ESCULENT FUNGUS, AGARIC GEORGII.

Some of the mushrooms show singular movements as the membranes are ruptured, the fibres squirming like a bunch of worms. As is the case in the movements of all other plants, it seems to have something to do with reproduction, and is useful in scattering spores. According to the authorities, most of the mushroom-shaped fungi [Fig. 21, Esculent Fungus] are either edible or harmless; the poisonous ones being the exception.

The fairy rings which play such an important part in juvenile literature, and which carry all through life a sense of delightful mystery, are all the work of the fungi. A single plant forms the centre of growth some distance under the ground; from this the mushroom mycelium spreads, sending out their delicate hyphæ, which extend equally on all sides, sucking up the moisture out of the ground, so that the grass above them dwindles. As the growth spreads outward radially, the inner hyphæ, having sucked all the organic matter out of the ground, perish, and in dying restore to the soil what it had lost. The circular plat of thin poor grass now becomes a ring as the grass grows in the middle again. By the same process the ring goes on enlarging. If the ground beneath it be dug up it will be found for a foot or more to be a tangle of hyphæ, the mycelium of the mushrooms or toadstools which spring up around the fairy circumference.

The colors of flowers are rivalled by the gorgeous tints of the mushrooms, crimson and orange, purple and brown, rose and blue, and a mingling of tints exquisitely tender and delicate. The form which is called in common language dry rot is a brilliant orange fungus growing upon a white cottony mycelium.

For a century and more lichens have offered an insoluble puzzle to naturalists. They grow every-

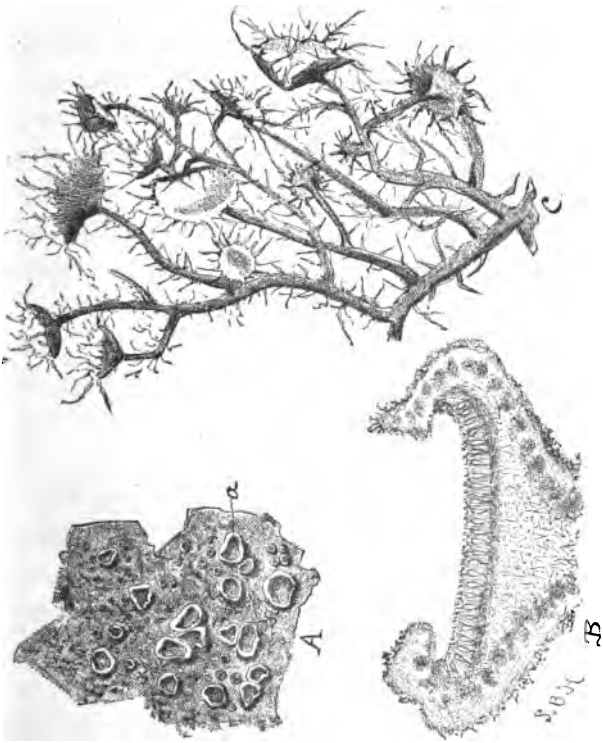


FIG. 22.
A, *Pertusaria Wulfenii*. B, Section of Apothecium of *Anaptychia ciliaris*.
C, *Usnea barbata*. [From Nature.]

where, encrusting rocks, and the bark of living trees, covering dead limbs and twigs with a delicate moss-like investment [Fig. 22.] They present many

features like the fungi, together with others which are incompatible with that idea, for they are always found with green cells, called gonidia, —supposed to be the fruit or spores of the plant. Late investigations by Schwendener have proved beyond a doubt that lichens are true fungi, which are parasitic upon various kinds of algæ: the gonidia being the algæ host; the lichen proper,—the leafy growth,—its fungus parasite. [Fig. 23.] In the illustration, *a*, *a* are algæ, *f* the

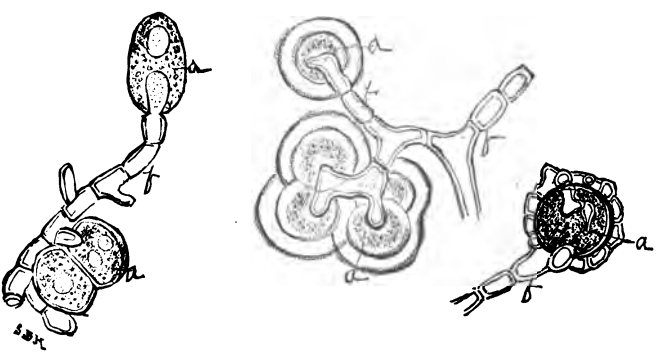


FIG. 23. ALGÆ AND PARASITIC FUNGUS.
a, Algæ; *f*, fungus.

fungus parasite. To put this question beyond doubt the matter has been subjected to long and exhaustive experimentation. The gonidia are found to live and multiply when separated from

the fungus, and to be unquestionably well-known algæ, while the parasite cannot develop without its host. Schwendener's views were put to a synthetical test by Bosnet, who sowed spores of certain lichens upon our old friend the protococcus. He found that they soon grew, and fastened themselves upon the algæ. It is not the water algæ but the kinds like protococcus and palmoglea which grow upon damp stones and moist wood that are chosen as hosts. It is accepted as a fact, by Sachs and most eminent physiological botanists, that all lichens are parasites, that they are true fungi, and that they live upon algæ hosts.

In parts of the world the lichens are very important, sometimes alone in their importance as articles of vegetable food. The food of the reindeer in Lapland is the *Cladonia raniferum*, a kind of lichen which grows under the snow. The reindeer is the only thing which makes human existence possible in these cold and sterile regions; he supplies the skins for tents and the means of getting from place to place; it is the reindeer's milk and flesh which give food in the long Arctic winters, and so sustain what life there is. The *tripe de roche*, another Arctic lichen, has proved the sole food that has kept alive

for weeks together the bands of brave adventurers who have tried to penetrate to the "open sea." All the desolate desert of snow would be as empty of human life as the sand wastes of Sahara if it were not for these insignificant vegetable forms, from which they directly or indirectly get their food.

CHAPTER IV.

LIVERWORTS AND MOSSES.

THERE seems to be in Nature some wonderful healing power which expresses itself in the most widely spread, even though they be the humblest, of her manifestations. Not more tenderly does the mother's hand cover with brightness and beauty the grave that holds her buried love and hope, than Nature heals over with creeping mosses and graceful ferns the unseemly wounds which man so ruthlessly makes in our beautiful earth. It sometimes seems as if nowhere was such scope given for the lavish expenditure of her resources, as that afforded by some such vandalism.

There is no form of organic life which reveals more that is wonderful and beautiful than does such humble life when subjected to the test of the microscope. Almost the first thing which presented itself as I opened the pages of Carpenter with the happy sense of possession, was the exquisite little bird's-nest cup with its treasure of gemmæ, which

may be seen in Fig. 31. Its beauty naturally created the desire to find the wonder itself, and to subject it to microscopic scrutiny. On one of our loveliest October days,—when Nature was holding her Carnival preparatory to her long and cheerless Lent,—a pilgrimage for this purpose was planned, and carried into execution; and a spot, loved of the liverworts, mosses, and ferns was found.

A walk over unequal railroad ties, with the usual roadside accompaniments of wretched Irish hovels and their hideous and disorderly surroundings, was hardly the tuning up one needed to fall quietly into the mood appropriate to an introduction into the fairy court where myriads of tiny creeping plants and waving fronds of fern were keeping gala-day.

Just by the side of the railway track rose a tall perpendicular bank of rock. The strata projecting here and there, after the rough handling of the pickaxe, afforded foothold to myriad forms of life. From the base to the crown of the artificial cliff, every square yard was covered with verdure; and over and through it all, the perpetual dripping of a gently running stream supplied the constant moisture in which such life delights, and without which it pines away and perishes.

In one of the horizontal ledges near the foot of the cliff, the patient water had hollowed out for itself a tiny basin which it forever filled and forever overflowed. Around this spring, every inch of rock was covered with the curling fronds of the *Marchantia polymorpha*,—each leaf clinging close to the bare rock by a thousand little rootlets. This was the very plant we were hoping to find; it is perhaps the commonest, and is certainly the most interesting, of the class called liverworts in the vernacular tongue, and hepaticæ by the botanists. It was one of those days when every thing went harmoniously; when matter seemed to have gotten the better of its "natural depravity," and to be all that, ideally, it should be. In spite of the lateness of the season, there were the flattened fronds with their curled-up edges; bearing upon tiny stalks which rose from the middle vein of the leaf, the female portion of the plant—the archegonial disks—in full and vigorous life [Fig. 24, A, *a*]. Upon the same frond, the cupules (A, *b*, *b*), holding their gemmæ or spores, were found in every stage of development. The only thing that was wanting was the antheridia.

The cupules bearing the gemmæ, instead of being sessile upon the fronds, as they are given in all the

figures which are commonly found, were, in the specimens examined, raised upon a small pedestal; the gemmæ themselves, however, were identical with those drawn by Sachs [Fig. 31].

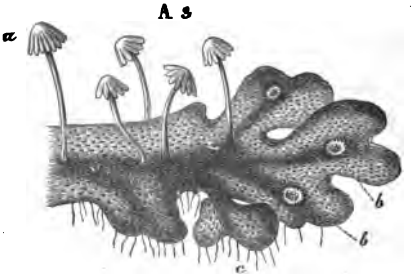


FIG. 24.

A, *a*, Archegonial disks; *b*, cupules bearing gemmæ; *c*, root-hairs. [From Nature.]

Hitherto, in our ascending series, we have examined no organisms of a very complex nature. The cells have been sometimes simple cellulose sacs, with their protoplasmic contents; sometimes an association, more or less complex, of such cells. There has been no considerable differentiation among them; they have been, in fact, like independent savages, sometimes living separately and performing, each one for itself, all the functions of life; or else they have been banded together for mutal protection.

The *Marchantia* give more than one striking illus-

tration of differentiation; that is, of cell development into special organs for the performance of special functions, and we have in this fact one of the dis-

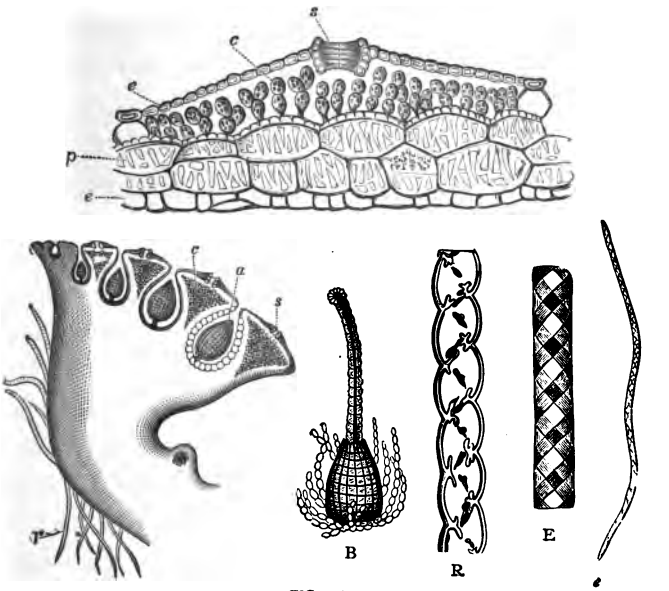


FIG. 25.

M, *M*, *polymorpha*, vertical section through a portion of the leaf showing series of cells; *e*, upper epidermal system of cells; *c*, chlorophyll cells; *p*, parenchymal cells; *e*, lower epidermis; *s*, vertical section of chimney-like stomata. A, section through antheridial disks; *c*, chlorophyll; *a*, antheridia; *s*, stomata; B, archegonia; R, root-hairs; E, *e*, elaters. [After Sachs.]

tinguishing characteristics, which marks it as a higher form of life than any of those already

studied. The fronds of *M. polymorpha* consist of several layers of cells [Fig. 25, M], a lower epidermal system, *e*, from which spring the root-hairs that enable them to cling so closely to rock surfaces; above this a series of parenchymal cells, *p*, with thickenings projecting inwardly reticulately; above this again, a large air-cavity in which the chlorophyll cells, *c*, grow up in a confervæ-like way, and finally an upper epidermal system, *e*. The leaf [Fig. 26], even under very low powers, shows itself to be covered with diamond-shaped or rhomboid markings. Each of these spaces [to be seen in vertical section, in Fig. 25] covers an air-chamber, and each possesses in the centre curiously formed stomata, or mouths for breathing. The epidermal cell, instead of dividing into two guard-cells,—as is usually the case in the formation of stomata,—divides and subdivides until a little chimney is built up of several courses of cells, each course being composed of four or nine cells. Down the throats of these tiny shafts it is quite possible to look by means of the microscope, and see the chlorophyl cells beneath. The lowest course, like the ordinary guard-cells of other stomata, possesses the power of contraction and expansion, and is called the "obturator ring." In

this way, each air-chamber beneath the green rhombs is in communication with the outside air,—the amount of communication which is kept up being regulated by the contraction and expansion of the obturator ring. Each of the rhombic plates is bounded by a band of colorless cells, which belong to the parenchymal system. A glance at Fig. 25, will show these points better than any description. In *M. polymorpha* there is a very marked alternation of generations,—a phenomenon already described, but which may be here briefly re-stated. In two or more successive generations, a form appears which is the result of a fertilized embryo, and from this a different form springs which is capable of reproduction without fertilization. We find ourselves, in beginning the life history of *M. polymorpha*, in the dilemma of the naturalist who could not determine how to begin his series,—whether with the bird or the egg. We will, however, begin with the spore and follow the two generations, sexual and asexual, till we reach the spore again. A new *Marchantia* begins its existence by the formation of a flat, leaf-like stem or thallus, composed of several layers of cells; this, as it grows, branches dichotomously, that is, the single stem divides into two.

From the under side of the leaf thus formed, root-hairs grow which fasten it to the ground; on the upper side develop the reproductive organs.

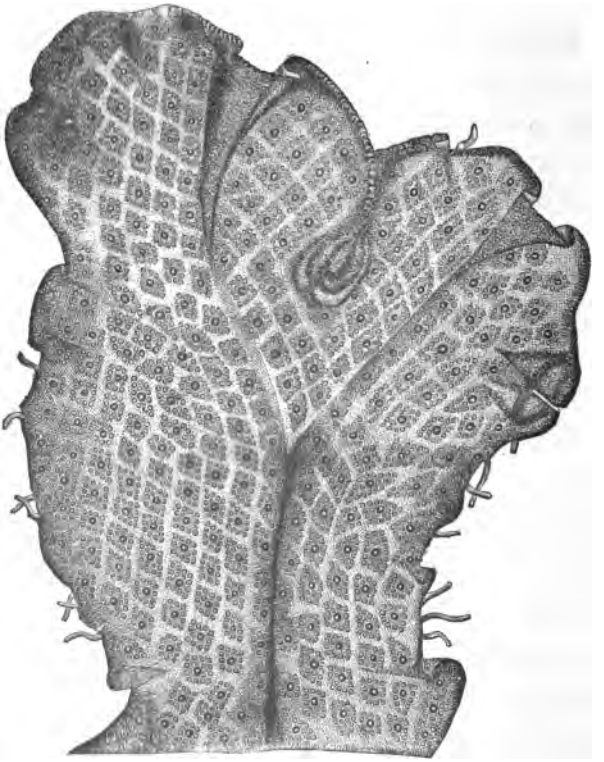


FIG. 26. LEAF OF M. POLYMORPHA UNDER LOW POWER. [FROM NATURE.]

From the leaf forms (the fronds, that is) spring

two inflorescences. As a general rule, one plant bears the antheridia—the male,—and another the archegonia—the female, form. In this case the term diœcious is applied; it sometimes happens, however, that both kinds are found upon the same frond, in which case it is called monœcious. The antheridial disk springing from the leaf form may be seen in Fig. 27. The upper surface of this disk has a number of flask-shaped depressions in its cellular tissue; in these the antheridia proper develop [Fig. 25, A, *a*]. The process begins by a cell, in the bottom of the still undeveloped flask-shaped cavity, showing a papilla-form swelling in the bottom not unlike the curved-up base of a wine bottle; this swelling is divided up into cells by a horizontal partition, or septum. The papilla thus formed again divides into an upper and lower cell; the lower cell forms the pedicle (or stem), the upper develops into the antheridia. This development of the antheridia is sufficiently like that of the gemmæ [Fig. 28, 1, 2, 3, 4, 5, 6] to

FIG. 27. ANTHERIDIAL DISK. [AFTER SACHS.]

need no separate figure to illustrate here. The division and the subdivision of the cells is shown in outline in the figures numbered consecutively in Fig. 28. The antheridium [Fig. 28, B] is an ovoid body with a single superficial layer of ordinary cells containing chlorophyll. Within this surface layer are crowded masses of the mother-cells of the antherozoids. The access of water swells the internal mass of cells so greatly that the surface layer gives way and the mother-cells escape; the antherozoids soon free themselves from their investment, and move about in the water with a rotating motion. They are long slender threads curved spirally from one to three times, with two long ciliæ by which they propel themselves. Usually they have attached to their anterior end a delicate vesicle which has been traced by Strasburger to the central vacuole of the mother-cell in which it was developed [Fig. 28, B].

The archegonia begin their development by the division and subdivision of a cell at the base of the receptacle in which they mature, exactly as we have described in the case of the antheridia. Between the fringed edges of the perichœtium [Fig. 29, A 2, *p*] this development takes place. A flask-shaped

body [Fig. 25, B], the archegonium, grows to ma-

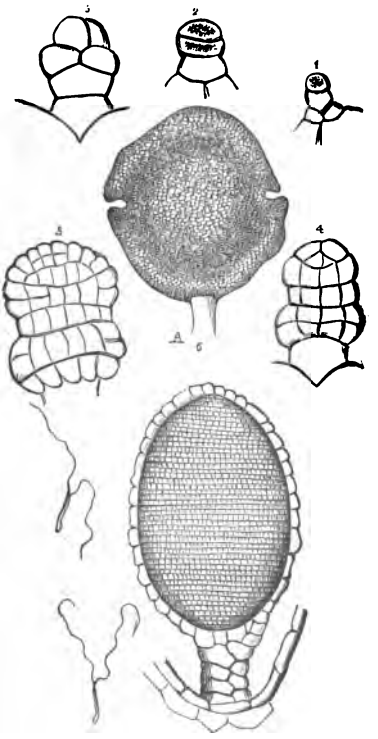


FIG. 28.

A 1, 2, 3, 4, 5, 6, Development of gemmæ; B, antheridium nearly ripe, and free antherozoids. [After Sachs.]

turity. The central cell in the bulging portion of

the archegonium develops into an ovule, and the cells above it extend themselves so as to form the

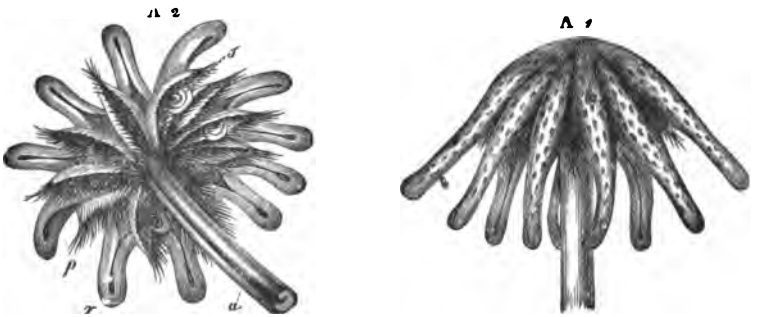


FIG. 29.

A 2, Archegonial disk as seen from below, showing sporogonium; *s*, sporogonium; *p*, perichœtium; *r*, radial outgrowths; *a*, stalk with double channel. A 1, Same, side view. [From Nature.]

neck. As the ovule approaches maturity, the central row of cells extending through the neck of the flask is converted into mucilage; in this way, a canal opens from the outside to the ovule itself, filled with a substance easily penetrable. The antherozoids, which by this time are freely swimming about, penetrate the mouth of the archegonium, traverse the canal, and fertilize the ovule. The fertilized ovule, or embryo, instead of directly developing into a new plant, goes through a transitional stage. The embryo cell develops into a mass of cells, within the bulging portion of the

archegonium. In its young stages, the mass of embryo cells, now called a sporogonium, is composed of polygonal cells; but a change soon shows itself between the external layer and its contents. The external layer cells elongate and become marked with internal spiral thickenings [Fig. 30], the internal cells develop into long slender filaments; some of these form elaters [Fig. 25, E, *c*], and others which are four or five times as thick, subdivide by cross septa into squarish masses which form ultimately the spores. Reproduction from the spores is very similar to that of the ferns—Chap. V [Fig. 36, A, B, C, D],—by the extrusion of a tubular process from one of its sides.

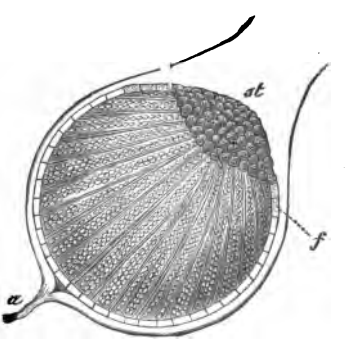
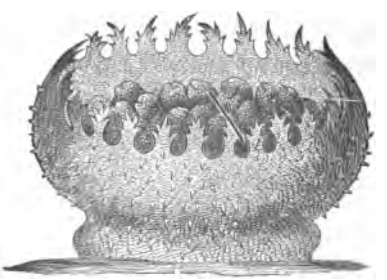


FIG. 30. SPOROGONIUM, SHOWING SPORES AND ELATERS. [AFTER SACHS.]

When the *Marchantia* develops in damp and shady situations favorable to its growth, the reproductive function, which very often bears a reciprocal relation to mere growth, does not so freely manifest itself. In this case, a form of asexual reproduction

takes the place of the sexual. The little nest-like cupules [Fig. 31] develop upon the frond. They appear first as a mere bulging of the epidermis; the outer layer splits open finally, forming a delicate fringed border of marvellous regularity and beauty. The cups themselves are green, but the fringed edges look as though they were made of glistening colorless glass. Within the cupule, tiny papillæ



CAPSULE WITH GEMMÆ. [FROM NATURE.]

grow up [Fig. 28, 1, 2, 3, 4, 5, 6]; by cell division they form into pedicel and gemmæ. The gemmæ are little oblong flattened disks with a notch on either side [Fig. 28, A, 6]; they are composed of two or more layers of cells, green, except the two or three rows about the edges, which are sometimes as pellucid as clear glass. After a time the disks spontaneously separate themselves from the pedi-

cels and lie in their cupules, from which they are generally washed by the rain.

The gemmæ, in germinating, send out from the two depressions on either side of their lateral edges two plates of cells which develop into a sort of double frond. Mirbel, who investigated this point with great accuracy, found that there was no bilaterality in the gemmæ themselves; that is, whichever way they fell upon the soil, the upper surface invariably developed stomata, and the lower, root-hairs. Thus either series of cells composing the gemmæ seems to be capable of developing as the case may be, stomata, or root-hairs; and the conditions under which it germinates alone determine which. After the process of development has begun, however, no reversal can be effected. A frond, no matter how minute, if turned over, will twist itself round in order to regain the position in which it had first developed.

The mosses belong to the same group as the liverworts, and follow very much the same method of growth and reproduction. The *Marchantia*, as we have seen, produces a thallus [leaf], from which spring the antheridia and archegonia,—the male and

female efflorescence. The mosses also produce a thallus from the growth of the spore, but this, in-

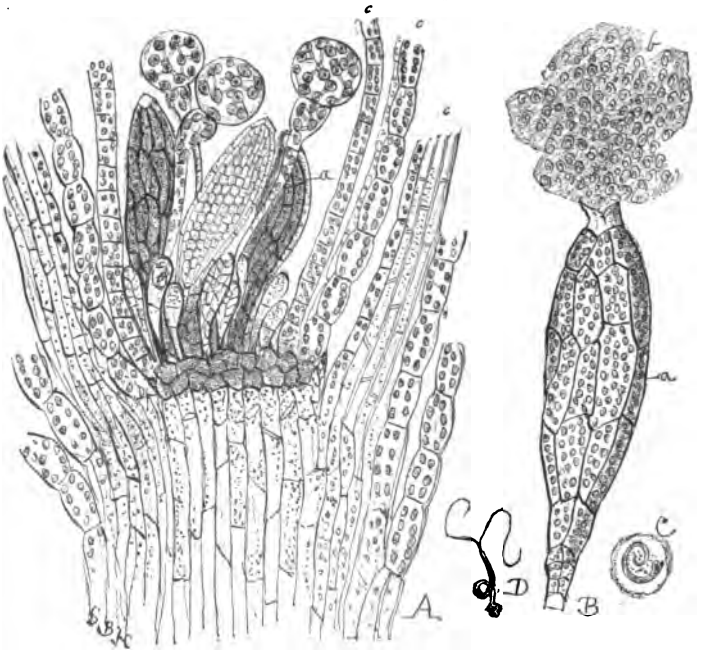


FIG. 32. ANTHERIDIA.

A, Antheridia *in situ*; *a*, antheridia; B, antheridium discharging antherozoids; *c*, antheroyoid coiled in cell; D, free antherozoid.

stead of producing at once these two reproductive bodies, sends out a lateral shoot; in the centre of a little tuft of leaves on the end of the branch grow the antheridia and archegonia. Fig. 32 gives a vertical

section of the male bud, *c*, *c*, representing the investing leaves, and *p* long bodies which grow between the antheridia. B. is the antheridium open and discharging the antherozoids. Fig. 33, B, is such a section of the archegonial bud, the female efflorescence. A is the archegonia further magnified; C, a sporogonium into which the fertilized ovule becomes developed; and D a section of the ripe sporogonium. The process of fertilization is almost identical with that in the *Marchantia*, the central row of cells melting away, leaving an opening to the ovules which the antherozoids whipping about enter, and the fertilization is effected. These two illustrations so clearly show the peculiarities of the reproductive organs that verbal description would be superfluous. Besides this mode of reproduction, the mosses have many ways of extending their lives by buds, stolons, or gemmæ; each branch, or root-hair, may begin a new plant on its own account, so that the life of the colony is extended indefinitely, the older parts often dying off while the new progress. The gemmæ are developed in many of the mosses in graceful cups, borne upon the end of a shoot. Fig. 34 gives the cup A, and a section through the cup B, showing the gemmæ as they grow, while at C may be seen a

very-much magnified gemma, showing its cellular structure.

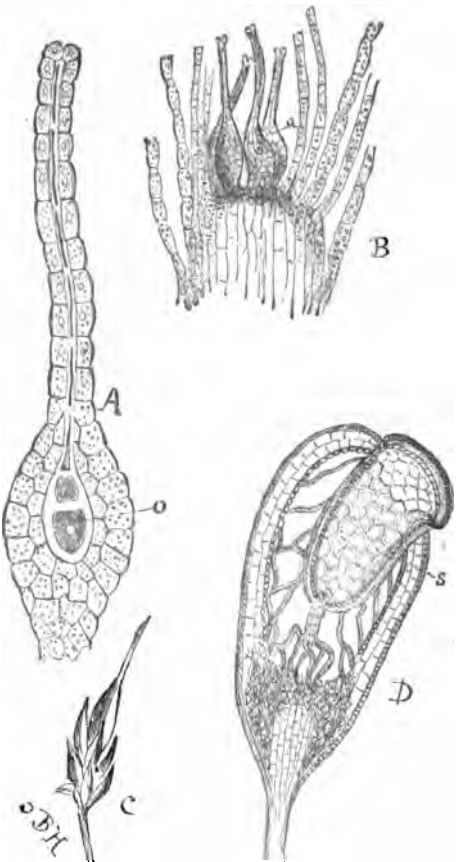


FIG. 33. ARCHEGONIA AND SPOROGONIUM.

A, Archegonium; B, archegonia *in situ;* C, sporogonium nearly ripe; D, section of sporogonium.

The mosses begin to show something like the differentiation of cells in their stems, that is found in the higher forms of vegetable life. In some species there is a trace of tissue, which seems a faint

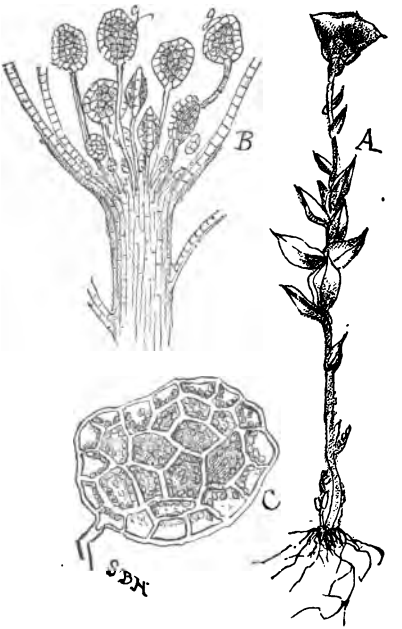


FIG. 34. GEMMA CUP AND GEMMÆ.
A, Gemma cup; B, gemmæ *in situ*; C, gemma magnified very much

prophecy of the bundles,—the air-vessels which run the length of the stems in the ferns and flowering plants; but it is a mere suggestion. Mosses have not attained the dignity of roots; they are nourished

and anchored by masses of interlacing root-hairs, making sometimes a dense felt, formed by the coiling or interlacing of the fibres.

One great division of mosses, the *Sphagnaceæ* or bog mosses, are very peculiar in certain ways. They begin like other mosses from a swelling on the surface of the spore; this grows and develops, the new plant nourishing itself by means of its root-hairs [Fig. 35, A]. Here and there, on the thallus, or on the root-hair, as the case may be, a new plant begins [*p*, Fig. 35, A]. At B, in the same figure, the new plant, further advanced, may be seen. The structure of the sphagnum leaf is very remarkable. When the young leaf begins to grow the cells are all alike; it is a flat tissue of cells only, one cell in thickness. After a while certain of the cells begin to grow larger, pressing those between them into a long, narrow shape; the large cells empty themselves of their contents; the narrow cells, which are full of protoplasm and chlorophyll bodies, form an interlacing net-work, all the interstices of which are occupied by the empty cells. The walls of these empty cells thicken in spiral rings or circles; the part of the wall enclosed in the circumference is absorbed, and forms circular openings into the empty cells. All the genus have leaves thus made up of

alternate systems of empty and full cells [Fig. 35, C].

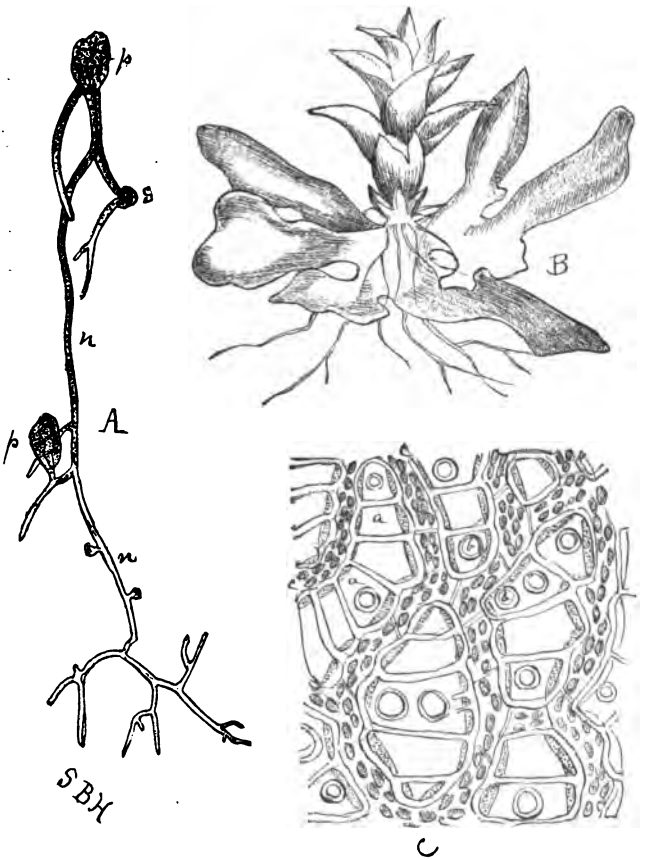


FIG. 35.

A, *Sphagnum auctifolium*; *s* spore; *n*, first growth; *p*, young plants; B, young plant; C, leaf of *sphagnum*: *a*, empty cells; *b*, openings; *c*, chlorophyll cells.

The antheridia of the sphagnum auctifolium is a graceful little urn with curled-over edges, which, when ripe, send out a cloud of antherozoids; the archegonia looks like a hazel-nut resting in a cup. The forms (of course under the microscope) are very exquisite, just what one might look for in the delicate and velvety coating which clothes many barren places of the earth. The sphagnum mosses grow in the most miserable spots, where the soil is very poor. Year after year, as the moss dies and a new crop grows over it, layers of vegetable mould are formed, which at last make the peat bogs like those of Ireland and other parts of the world.

Some branches of the sphagnum mosses are found in our Southern States. *S. Mulleri* grows in the mountainous regions of North Carolina and parts of South Carolina and Mississippi. Are they building up peat bogs for the future American?

CHAPTER V.

FERNS.

THE ferns are the first in importance of the great group called by botanists the vascular cryptogams. A differentiation of cells, for the purposes of organic growth and reproduction, has been found in the liverwort, which we have just been considering; but in the ferns, something higher than this manifests itself. We find in their stems the intricate series of differentiated cells which form the parenchyma,—the fibro-vascular bundles of pitted, spiral, reticulated, and scalariform vessels, already described in Chapter I. This fibro-vascular system penetrates not only the stems of ferns, but also the roots, which first appear in this group. This gives them the name of vascular; cryptogam, or hidden marriage, refers to the mode of reproduction, which is like that of *Marchantia*, without flowers.

Their growth and cell division for the formation of special organs of great complexity and delicacy bind the ferns, on the one hand, to the highest

forms of vegetable life; while their modes of reproduction bind them, on the other, to the lower. Like the most perfect manifestations of vegetable life, they are vascular; like the lowly mosses and creeping hepaticæ, they are cryptogamous.

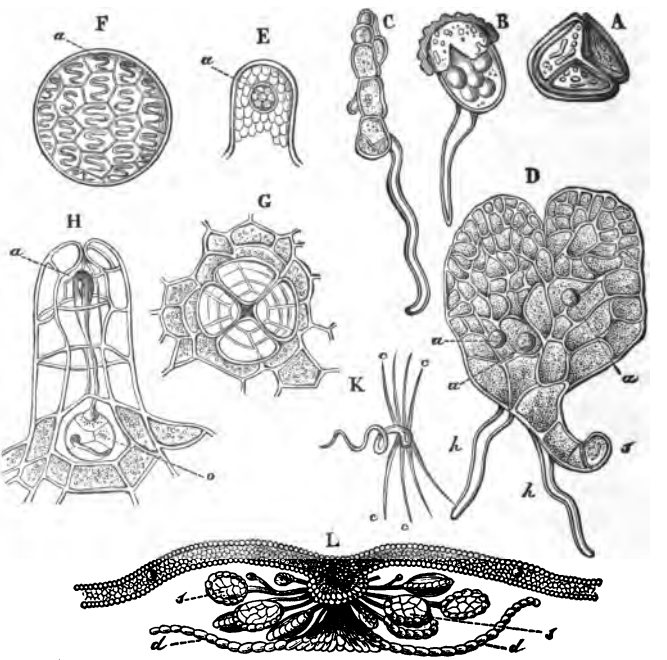


FIG. 36. PTERIS SERRULATA.

A, B, C, D, Development of fern from spore A to prothallium D. D, *a*, Early stage in development of archegonia, or female portion of plant; *h*, *h*, root-hairs. E, Developing antheridium, or male portion. F, Antheridium, with antherozoids, *a*, in mother-cells. G, Developing archegonium. H, Ripe archegonium, which has been penetrated by antherozoid and its ovule, *a*, fertilized. K, Moving antherozoid. L, Transverse section of *Aspidium*: *d*, indusium; *s*, sporogonia attached to midrib. [After Carpenter.]

The development from spores is very like that of *Marchantia.* The spores [Fig. 36, A], set free by

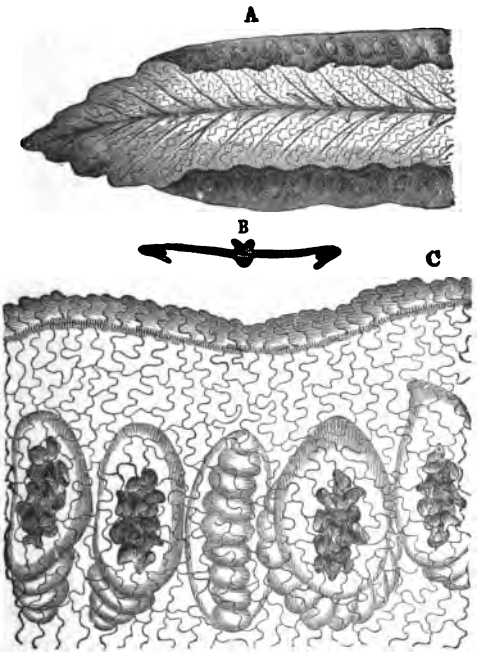


FIG. 37. PTERIS SERRULATA.

A, Leaf slightly magnified, showing sporangia within folded edge of leaf; B, transverse section of leaf; C, indusium and sporangia much magnified. [From Nature.]

the rupture of their investing theca, have a yellowish or brownish outer coat, often beautifully marked like pollen grains. When placed under favorable condi-

tions, in a damp place, with plenty of light and warmth, the spore shows a slight enlargement, accompanied by a rounding off of its angles; the internal cell wall sends out, through an aperture in the external coat, a tubular prolongation [Fig. 36, B]. This rootlet absorbs sufficient moisture (and conveys it to the cell) to cause it to distend and rupture the hard outer spore coat.

The cell then begins to extend itself by cell division at the end opposite the root end, C. These cells divide, not only longitudinally, but also transversely; and a plate of cell tissue, so much like a *Marchantia* frond, is the result, that it may be very easily mistaken for one.

This first leaf, D,—or prothallium, as it is called,—is essentially the same in all the ferns. Its under surface always develops the root-fibres, by which it fixes itself to the soil, and it also produces both the antheridia and archegonia, by which it is sexually reproduced. The antheridia may be early distinguished [Fig. 36, D, *a*]. They begin as a slight protrusion, which shows itself in one of the prothallium cells; this is at first filled with chlorophyll, but soon a central free cell, E, *a*, may be seen, which soon develops into an enclosure filled with a brood of other

Masterpieces of Literature.

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cells. After a time, each of the enclosed cells is seen, and contains a spirally coiled filament, the antherozoid [F, *a*]. The archegonia are fewer in number, and are developed on another part of the prothallium ; a slight elevation of the cellular layer of the prothallium, within which is the ovule, makes its appearance, and grows, something like the archegonia of *Marchantia*, to maturity. The fertilization of the ovule, and its conversion into an embryo, may be seen in the same figure. [Fig. 36, H, archegonia ; *a*, antherozoid ; *o*, ovule.] The development in ferns, from the embryo to the plant, is direct ; unlike the *Marchantia*, which goes through the transitional asexual form of a sporogonium before the true plant is formed. The cells of the new plant are developed directly from the embryo by cell division ; it soon bursts from the archegonium, and becomes a new plant.

In the *Marchantia* and the mosses, the vegetative and the sexual generations are often carried on simultaneously. As we reach the ferns we find a regular alternation ; from the spore is developed the prothallium, on which the antheridia and archegonia are formed, and these, by the union of the two reproductive cells, produce the familiar fern plant.

The vegetable hairs, or trichomes, of ferns, are produced in great numbers. The antheridia and archegonia are merely modified surface-hairs; they are, really, mere outgrowths of the epidermal layer of cells. True root-hairs, which are simple hairs formed of a single cell elongated enormously, develop upon roots, underground stems, and the bases of leaf-stalks. On creeping stems, brownish, many-celled hairs arise, called palæ. In some varieties, strong bristles of considerable length are formed; and often, fine, delicate, articulated hairs. The sporangia themselves are merely metamorphosed surface cells, and so, are morphologically trichomes.

The little brown markings upon the back of fern leaves in fruiting-time are collections of sori, or a single sorus, each sorus being, in its turn, composed of a number of sporangia containing spores. The whole sorus is generally covered by an outgrowth of the leaf. In Fig. 36, L, the epidermal cells of the midrib—the leaf being seen in a vertical section—have developed into a plate of tissue which encloses the mass of sporangia. In this case, the investing portion is called the true indusium. Sometimes the spore-cases are covered over by an outgrowth, not only of the surface layers of cells, but of the

entire leaf; it is then called the false indusium. In some species, *Pteris serrulatus*, for instance [Fig. 37, A], the whole edge of the leaf is doubled over,

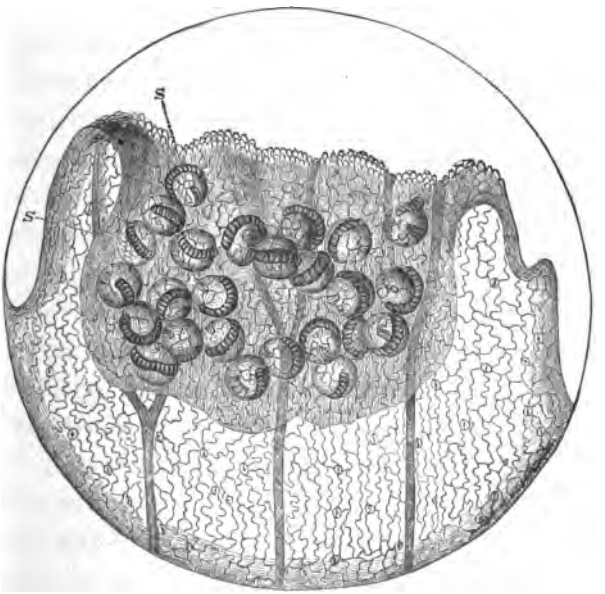


FIG. 38. ADIANTUM CUNEATUM.—END OF LEAF FOLDED OVER TO HOLD SORUS. S, Sporangia containing spores. [From Nature.]

and so holds the sori. In the highly magnified portion [Fig. 37, C], the sporangia may be distinctly seen. The spores are contained in a closed sac, formed of a single cellular layer, and surrounded by

a ring of peculiarly developed cells, called the annulus [C, *a*, *a*]. By the contraction of this ring, when dried, the sac holding the spores is ruptured, and the spores themselves are liberated.

Spore-cases are not, as a general thing, formed upon all the leaves of the plant. There are sterile leaves and fertile leaves; on some varieties, these two kinds of leaves regularly alternate on the stem. The sori are also very differently distributed over the fertile leaves. Sometimes they are regularly distributed over the whole under-surface of the leaf; sometimes they are collected in definite spots; and sometimes, again, they are arranged in beautifully reticulated patterns. The *Osmunda regalis*—or flowering fern, as it is incorrectly called—bears what appear to be panicles of flowers or fruit; but this appearance is due to the fact that the fertile leaves are all at the upper extremity of the frond, and that all portions of the leaf disappear, except the veins and other parts which bear the fruit [Fig. 39].

This is also true of the Hartford fern, figured on the cover, a beautiful trailing fern much used in decoration; almost all the leaf tissue of the last leaves on the stem have disappeared, leaving only the veined portions which bear the sori.

Ferns, which in our climate and era form so insignificant a feature in vegetation, attain to enormous proportions in tropical countries. The erect stem in the great tree-ferns of the torrid zones not infrequently rises to the height of fifty feet before the great fronds which crown their tops spring from the columnar trunk. In the woods of the carboniferous era, the enormous trunks and plumy foliage of gigantic tree-ferns form a conspicuous feature; but, like many of the monsters which ruled in the animal and vegetable world in those old days before man had come upon the earth, they have since sunk into comparative obscurity and insignificance, and have given place to a life which, if it be not more luxuriant, and beautiful, and wonderful, at least approaches more and more nearly to the ideal type

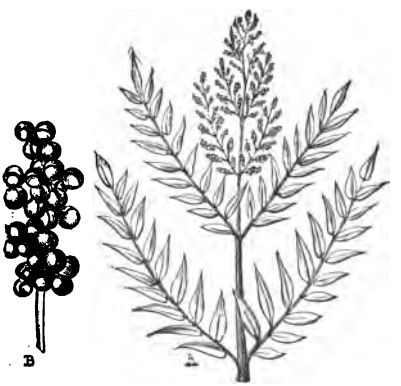


FIG. 39. OSMUNDA REGALIS WITH ORDINARY AND PERTILE LEAVES.

of perfection, toward which nature, animate and inanimate, has been reaching through infinite ages; spelling out slowly, but surely, the Divine purpose in creation, which is forever at one with itself.

CHAPTER VI.

PHYSIOLOGY OF PLANTS.

A FEW words upon the physiology of plants seems absolutely necessary to make clear some of the processes of growth. It has been impossible all along to study the life-history of any plant without bringing in some allusion to, or some explanation of, these physiological processes. At the risk of occasional repetition, some of these points will be briefly recapitulated, and others newly stated, in this short chapter devoted to the purpose.

There can be no life without the presence of water: just as the human body will perish when it has lost a certain percentage of the water which keeps every portion of its flesh soft and pliant, so the plant will die when a definite and proportionate amount of its moisture is abstracted. There are two causes always at work within the living tissues of a plant which occasion the upward flow of water. The process of growth and assimilation—the first of these two causes—demands a constant supply of

moisture. Such cells or organs as need water supply themselves from the adjacent cells below; they, in their turn, making a demand upon the cells beyond and behind them, till finally the extreme fibrillæ of the roots are reached, when the necessary water must be supplied from without or the plant will wither and die. These currents proceed slowly, as does the growth itself. The second cause of this upward flow of water is the enormous evaporation which takes place from foliage leaves. An immense surface, in proportion to its volume, is presented to the dry air in every ordinary plant. There is a constant exhalation of moisture, in consequence of a vital process akin to animal perspiration as well as from mere evaporation. A single sun-flower, it has been determined by careful experiment, yields up twenty ounces of water in the course of twelve hours. The leaves of the wild cornel have been known to exhale twice their own weight of water in twenty-four hours. Some idea of the demand from above upon the water supply below may be gained from these facts. Besides the vital process, by which water is conveyed from cell to cell, the moisture is drawn up from the earth through the tissues of the plant, just as the oil of a burning lamp is drawn up by capillary

attraction, and so long as the supply equals the demand, the plant remains fresh, or turgid: when evaporation ceases in consequence of the extreme moisture of the surrounding air, the current of water also ceases to flow. It is found that those trees which put out only a definite number of leaves in the spring, and do not increase their foliage in summer, are those that transpire most rapidly; and if every other portion of the tree be destroyed, the current will still maintain a steady flow through the woody fibre; it is therefore inferred that the current of water induced by evaporation has no immediate and necessary connection with the processes of growth and nutrition. In many plants possessed of a thick cuticle, all the evaporation takes place through the stomata; its amount then depends upon their number and character. The stomata developed upon the vegetation of our high and arid Western plains, the cactus, for instance, are so formed as to retain most of the moisture received from below; in this way certain forms of life are possible, even under the unfavorable conditions there found.

In evaporation, not only the moisture of the woody fibre is dispersed, but also a large quantity of the vital fluid—the cell sap—is given off. In

order to determine the peculiar cellular tissue which performs the office of conveying water, branches of white iris or deutzia may be placed in a dark aqueous solution of aniline. In a little time the stems have taken up the colored liquid and conveyed it to the petals, and every delicate white leaf is veined with deep blue, the woody fibre alone having taken up the coloring matter. This beautiful effect lasts only for a few moments, for the aniline poisons the petals, and immediately destroys the tissue.

There are many movements of plants which bear a close relation to the processes of reproduction that will be mentioned later; but a few may be noticed here There are also spontaneous movements of plants which are merely due to growth, or the change, in shape and size, of the walls of their constituent cells. But those which we shall here speak of are the movements of fully developed plants, due to irritation. A large number of these are familiar to all in the opening and shutting of flowers, and take place under the influence of light, or heat, or both. All organs which show this capacity for motion are leaves—either foliage leaves or their modifications in the different portions of flowers; and the cause seems always to be the access, or loss, of water.

In a few familiar instances vegetable structures are sensitive to touch; most of these can be seen to bear a close relation to reproduction, but there is no physiological significance to others, so far as is now known. The opening and closing of flowers is akin to our waking and sleeping; and this change is generally dependent upon the action of light, either one way or the other. At night the leaves of the bean rise up, while the robinias hang down. Sleep, whether it be by day or night, is as essential to vegetable as it is to animal life, and plants as well as animals may be tortured to death by depriving them of their necessary repose. The sensitive plant, Le Maout tells us, faints, rather than sleeps, at a touch.

Leaves constantly turn one side toward and the other away from the sun; if they are twisted into the reverse position, if it can be done, they turn themselves back, and if it cannot, they die. When a branch is artificially reversed and secured, the petiole (or stem) of each leaf twists itself till the normal position is regained. This movement of the leaf is found to be independent of its need of light, as it takes place with equal certainty under water and in the darkness.

What follows has been already said, but it seems

best to repeat here. About one-half the dry weight of plants is carbon, and this is all obtained from the carbon anhydride—or carbonic acid—of the air, which constitutes only .0004, or $\frac{1}{2500}$ of its volume. Plants, it is known, reverse the process of animals,—that is, they inhale carbonic acid and exhale oxygen ; but this is not in consequence of respiration. Plants, like animals, inhale oxygen, and yield up to the air a nearly equal volume of carbon dioxide: this chemical action is performed by all the superficial growing cells, and at all times alike. In addition to this, the chlorophyll cells have the property, under the controlling power of sunlight, of absorbing carbon anhydride from the outside air, of decomposing it into its constituent elements, of appropriating the carbon for the building up of its tissue, and of liberating the now free oxygen. This is a process of assimilation rather than of respiration. The appropriation of free oxygen from the air, and the giving a portion of it back in union with carbon, as carbonic acid, is the true respiration of plants as it is of animals. During the day the more powerful effect of assimilation is observed. At night, when that ceases altogether, the result of true breathing can be noticed. A number of experiments made by the French scientist Boussin-

gault prove that, as a final result, far more oxygen is liberated by assimilation than is consumed by respiration. All the intercellular cavities, the air-vessels, and open woody fibre together form a continuous system throughout the body of the plant. At the root end all the ramifications of the system are closed, while at the other end it opens out to the air by means of the millions upon millions of stomata upon the branches, and especially on the under sides of the leaves. Throughout this ramifying system in roots and stems the gases necessary to the life of the plant continually circulate.

It is perfectly clear that as the process of assimilation must go on by the action of chlorophyll under the influence of sunlight, all the cells of the plant cannot take part in it. This appropriation of carbonic acid can only be effected by cells lying near the surface in stems and by leaves. In the words of Huxley and Martin's "Biology," "it can be proved experimentally that green leaves possess this power to a remarkable extent."

On the other hand, it is clear that when a plant is grown under the conditions described, the nitrogenous and mineral constituents of its food can reach the leaves only by passing from the roots,

where they are absorbed, through the stem to the leaves. And at whatever parts of the plant the nitrogenous and mineral constituents derived from the roots are combined with the carbon fixed in the leaves, the resulting compound must be diffused thence in order to reach the deep-seated cells, such, for instance, as those of the cambium [multiplying] layer, and those of the roots which are growing and multiplying and yet have no power of extracting carbon directly from carbonic anhydride. In fact, those cells which contain no chlorophyll and are out of the reach of light, must live after the fashion of torula, and manufacture their "protein" out of some material other than carbonic acid. "Thus the higher plant combines within itself the two physiologically distinct lower types of the fungus and the alga."

It is considered probable that all vegetable cells at some stage of their development manifest a curious circulation of their protoplasmic contents known as cyclosis. This consists in the steady flow of one or more currents of protoplasm over the inner surface of the cell wall. One of the most striking instances of this occurs in the cells of *Valisneria spiralis* [Figs. 43 and 44]. Another in *Anacharis alsinastum*, a

very common and obnoxious water weed. The most interesting cases are perhaps the following: nitella is a small water weed composed of exceptionally large cells whose envelope is transparent. It is therefore possible, under a very moderate power, to observe the flow of the protoplasm. The terminal cell of the leaf is of a cylindrical form, tapering suddenly to a point at the extremity. Under a moderate power, this cell looks about one inch and a half broad before it begins to taper. The whole surface of the cell, which is colorless, or almost so, is studded in a perfectly regular way with tiny bright green spots, except along two lines, which run from the base to the apex and on opposite sides of the cell. Suppose one of these green-studded sides to be turned toward the eye; a steady current of colorless protoplasm may be seen flowing down one side of the leaf, bending back at the point, and flowing up again on the other side. In this current are borne a large number of irregularly shaped masses of brilliantly but delicately colored green protoplasm. Among these are scattered other curious protoplasmic masses: round green balls, beset with spines of the same color, like a spherical sea-urchin, or a lively chestnut burr, carved in miniature, of pure emerald. There are, of

course, two lines along the longitudinal direction of the cell where the edges of these two opposing currents touch, and where their motion is neutralized; these two neutral lines are those before spoken of as not marked by the fixed green studdings. Now turn the cylindrical leaf half over on its side, so that one of these neutral lines is toward the eye. The protoplasmic current can then be seen pouring down one side of the inner surface of the leaf, and up the other, bearing its lovely green craft upon and within its bosom.

Almost as beautiful an example of cyclosis may be seen with a low power of the microscope in the purple hairs of the tradescantia, or in those of the common nettle. The current itself is colored in that case, and bears no bodies along with it, but the beauty of the delicate amethystine flood can scarcely be surpassed.

Many other curious phenomena in plant life, such as the chemical effects of heat, light, and electricity upon growth, the wonderful means by which plants climb and cling, the movements of roots and stems and leaves as they grow, must all be omitted for want of space.

CHAPTER VII.

CORN AND ITS CONGENERS.

THE ferns conclude the series of vascular cryptogams, and introduce us to the highest group in the vegetable kingdom, the phanerogams. The nearest term which popular language supplies to designate these plants is the flowering plants, though this is not strictly accurate. All the common forest and fruit trees, the flowering shrubs and plants, are included in the group, but many other less familiar forms also find place here.

The dim prophecies that have been struggling for utterance through all the language of vegetable life, here find their fulfilment. The root, which had no representative in the single-celled plant or the filamentous, algæ, which was represented by the mycelium of the fungus, the root-hair of the liverwort and the mosses, has reached the more complex rhizome in the ferns, but still falls short of the specialization which determines the true root of phanerogams. A similar process of development in the stems of

plants may be watched from its earliest beginning to the wonderful bundles of spiral, pitted, scalariform, and sieve vessels of the ferns which make its fibro-vascular system, and ally it to the still greater perfection found in the flowering plants and trees. If this slow blossoming out into the ideal type, in the vegetable kingdom; this reaching through infinite varieties and species and genera toward the highest expression of plant-life, could be studied through all its intermediate forms, the continuity would seem more remarkable than is possible when only certain groups are selected for examination. These groups are the most prominent, it is true, and are arranged in correct order, but they are not a sequence, and it is impossible by the closest study of links here and there, to take in fully the idea of continuity—to see clearly the wonderful chain that binds into unity the dimmest ages of the geologic past with the present day;—the humblest vegetable cell that finds its world in a drop of water, to the noblest tree that grows in the primeval forest.

While there has been this steady development in type, there has been along with it many minor fluctuations; forms that now occupy a low position in the scale, once reached enormous magnitude

or exquisite perfection. The advance of the type has often meant a retrogression in importance of certain groups or classes. Those who have been leaders fall into rank, subordinated to the nobler forms which succeed them. This fluctuation may be seen not only in classes, but also in phenomena. The alternation of generations which it has been impossible to detect in the lowest forms, rises to great importance in the liverworts and mosses, begins to show less marked features in the ferns, is almost entirely concealed in the phanerogams. The prothallium of ferns, which bears the ovules and antherozoids, and which with them constitutes the sexual generation, has almost lost its character as an independent plant; the spore-bearing fern plant, so familiar to every one, is the important part of the organism—the asexual generation.

Phanerogams, which include the palms and cone-bearing trees, as well as the flowering plants, show a still further deterioration in size and importance of the sexual, and a corresponding increase of the asexual, generation. The prothallium, which in ferns bears the archegonia and ovule, is reduced in the phanerogams to a mere part of the embryo sac, while the male prothallium with its antheridia and antherozoids is represented by the pollen cell.

Besides the palm and cone-bearing trees, and some other curious plants belonging to the gnetaceæ, which we shall have to omit, are the two great classes called monocotyledons and dicotyledons, having many features in common in regard to their modes of growth, development, and reproduction, and yet essentially different in certain very important particulars.

These two classes include all the flowering plants; that is, all which bear pollen and ovule, and are reproduced from seed, no matter how little like our common idea of a blossom the "flower" may be. The stems, and leaves, and flowers are morphologically the same; that is, they are mere modifications of the same cell structure.

There is a remarkable resemblance between the stem, the ascending, and the root, the descending, axis of the plant. The system of fibro-vascular bundles, the cellular and intercellular systems of fluid- and air-conducting vessels of both stem and root, are continuous; the mode of branching and of growth by cell division are alike in both, though the functions performed by stem and root are so different. The stem serves to support the leaves and flowers and to carry to them their food and drink; the root is the stomach which gathers from the earth and

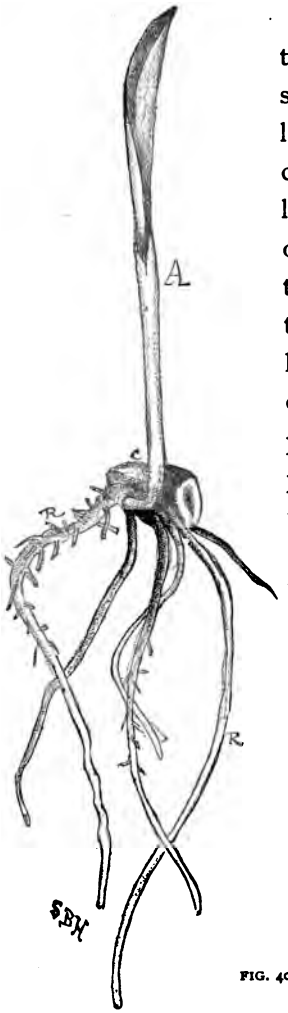
assimilates the nourishment and water necessary to the life of the plant: and yet in structure these organs are so little different. The root, morphologically defined, is only such an outgrowth of the substance of a plant as is clothed with a peculiar layer of tissue called the root cap. It is an *endogenous* growth—that is, it proceeds from the inner part of the cell tissue of the plant; while lateral shoots, vegetable hairs, and leaves are *exogenous*, or proceed from a layer of growing cells just underneath the bark.

The flower, as already said, consists generally of the reproductive organs, the pistils and stamens, and the axial structure that bears them. When the pistils and stamens make their appearance, the floral axis ceases to grow,—development by growth and development by reproduction being commonly reciprocal.

Among the monocotyledons many flowers are not perfectly developed in all their parts. The calyx, or corolla, or one of the reproductive organs is often suppressed. The plants are sometimes monœcious—that is, unisexual flowers are formed on a single plant, some bearing only the ovule, some only the pollen, some female or some male; or they may be diœcious, that is, the different sexes are borne upon separate plants; or they may be hermaphrodite (the most

common form)—that is, ovule and pollen are both developed upon each flower.

In order to understand the peculiarities of the monocotyledons, it will be well to select a single plant and study it from the beginning, throughout its life history. The name monocotyledon is derived from the fact that these plants send up first a single *seed leaf*, or cotyledon, after which come the true leaves, often unlike this first one. Indian corn is one of the most interesting of the simpler monocotyledons. Let a grain of ripe seed corn be soaked overnight and then planted in loose, rich earth. In three days' time the green will be seen piercing the soil. If then the hand be carefully passed some inches beneath the planted corn, and the plant, earth and all, be lifted gently up, the loose earth shaken from the roots and stem, we will have a perfect, though immature, organism. In these few days the simple outgrowth of parenchymal cells has become modified so as to perform their various functions: the root is perfect; and as a true and perfect root has not yet been described, we will look into its structure, and that which constitutes it a root, in contradistinction to rhizomes and root-hairs. [Fig. 40, A.]



It will be remembered that the cell by whose division stems and leaves are formed, lies on the outermost row of cells, or at the point of the leaf. In root-hairs and other outgrowths which perform the office of roots, this is also the case; but a true root has its apical cell, not at the extremity, but within, and protected by a cap of simple parenchymal cells. Some of the cells of the root cap will frequently shake off, showing how slightly they are attached. Each little rootlet which the corn grain has sent

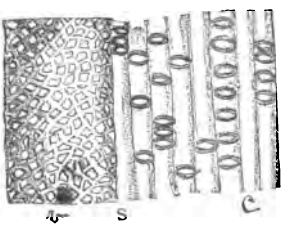


FIG. 40. A. CORN PLANT; *c*, vertical section of stem.

downward, shows this peculiarity of structure; and by carefully splitting the extreme end of an unbroken rootlet, the structure may be seen under a moderate power of the microscope with perfect distinctness. The ascending axis or stem also shows, at this early stage of growth, a marked differentiation of cells; the epidermis is formed, and a cross-section of the stem shows a number of thickened cells, which later on are most beautiful objects when magnified. The corn is an endogenous plant; it does not increase by a deposition of new cells outside the central woody fibre and beneath the bark, but altogether within; monocotyledons are always endogenous. The young leaf shows its cells filled with chlorophyll, and covered with a protecting cuticle; the surface of the leaves is thickly studded with numerous stomata [Fig. 5, Chap. I, B], which look something like the cleft side of a coffee-grain, or a pair of very full lips; through these little parted lips the respiration of the plant goes on. While the root is drawing from the soil water and nitrogenous matter, the cells within the stomata are appropriating the nutritious and life-giving elements of the air. Plants derive the larger part of their nutriment from the gases of the air, which is

the reason why certain hardy trees can live in the clefts of the rock where there is scarcely any earth from which to suck up nourishment and water.

As our little cornstalk grows, the thickened cells are collected into groups all through the central pith of the stem. Cut across any half-grown cornstalk, and it will be seen to be formed of a succulent translucent substance, dotted all over with opaque white spots; now cut a longitudinal section, and the dots will be seen to be a mere cross-cut of a longitudinal fibre. This stringy white fibre is beautiful beyond description under the microscope. It is a fibro-vascular bundle, made up of the long cylindrical tubes already described in Chapter I.—whose walls are here marked with spiral groovings, delicately sculptured indentations, and other forms of ornamentation. [Figs. 40, *c*, and 41, A and B.]

The fructification of the corn is most curious and beautiful. Every one is familiar with the look of the tassel, the cluster at the top of the stalk, and of the corn-silk, which hangs out of the upper part of the ear when it is forming. The tassel ripens first. Under a low power of the microscope, and even by careful scrutiny with the unassisted eye, it is seen to be made up of a number of minute bell-shaped

spathes. When ripe these open, and four anthers

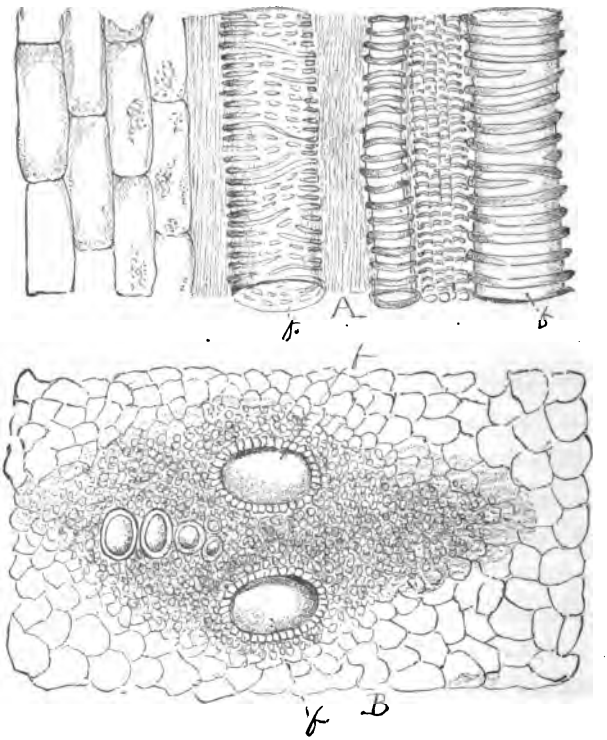


FIG. 41.

A, Vertical, and B, cross-section of fibro vascular bundle of corn. [From Nature.]

hanging by a flexible stem, depend. [Fig 42, A.]

The pollen (minute white translucent spheres) is

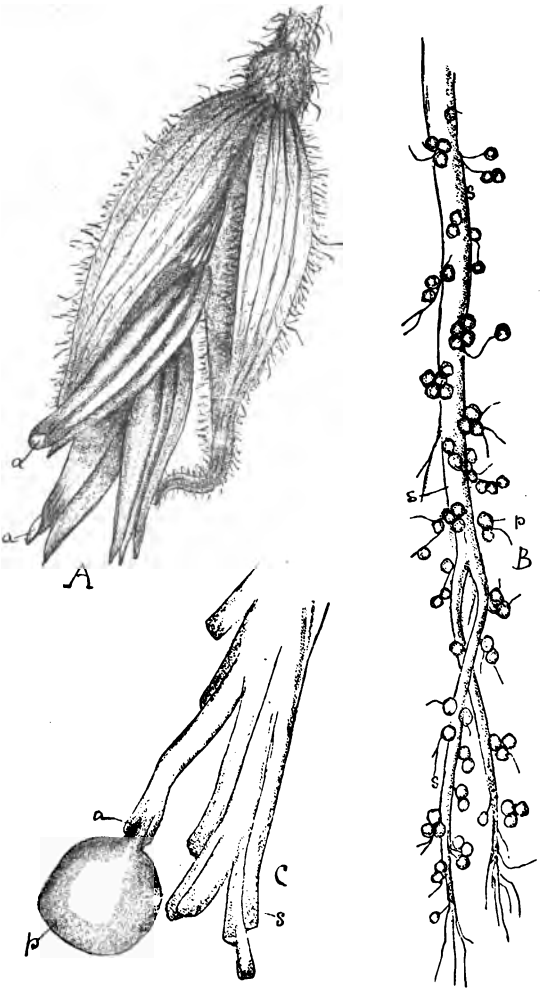


FIG. 42. CORN TASSEL AND SILK.

A, Single-tassel flower ; *a*, open end of anther ; B, silk with adherent pollen grains ; *p*, pollen ; *s*, silk ; C, pollination of silk. [From Nature.]

poured out of the apertures at the ends of the lobes, and fills the air with white dust. Below the tassel the ear of corn is forming; from each unfertilized ovule—the incipient grain—a long silky thread proceeds. These project as the corn-silk from the apex of the enveloping husks of the ear. The shower of pollen pouring down from myriads of dependent anthers above, naturally falls upon the silk, and is detained there by its slight stickiness and branching fibres. In a little while the stickiness and moisture of the silk induces a peculiar growth from the pollen grain. An increase of the inner protoplasmic substance takes place, as in the case of the fern spore already described; the wall of the pollen grain extending so as to cover the cylindrical protuberance. This tiny tube grows with marvellous rapidity, penetrating the loose cellular tissue of the corn-silk, and growing down and down through its whole length, till the ovule at its base is reached. [Fig. 42, B and C.]

The pollen grain was a single cell at first, and all this growth which extends its size to the entire length of the corn-silk, does not take place in the usual way by cell division, but grain, tube, and all remain a single cell to the end. When the extreme

end of the tube has reached the ovule, and penetrated into the interior tissue, the whole contents of the pollen grain are poured into the ovule, and then the grain of corn begins to grow and mature. Unless it is so fertilized, the grain, after a certain small amount of development, contracts and finally disappears. The missing grains on an ear of corn are simply the ovules which were never fertilized, and so have shrunken away and perished.

It is very well understood as a practical thing, that a solitary stalk of corn rarely or never produces a perfect ear, because the pollen of its own tassel is frequently blown about so that every ovule does not receive fertilization. But in a field or plat of corn the hundreds of stalks are pouring each its millions upon millions of pollen grains upon the air, till it is laden with the delicate dust, and each strand of corn-silk generally receives not one, but many grains of pollen, some one of which is almost sure to reach the ovule and fertilize it. It is also very well known that two kinds of corn, field-corn, for instance, and sugar-corn or pop-corn, should not be planted close together, if purity of the species is desired. The pollen of one plant is apt to fertilize the ovule of another, the newly formed grain telling the story of its mixed parentage.

The growth of the monocotyledons is utterly unlike that of the dicotyledons. The fibro-vascular bundles which form the veins of the leaves, run on into the stem from the insertions of the leaves. These pass obliquely downward into it, and then again bend outward as they descend, approaching gradually the surface of the stem. The common bundle is usually thickest and most perfectly developed at the curved portion which lies deepest in the stem, while the arm which bends out toward the leaf becomes thinner and simpler upward, and the descending arm of the bundle behaves similarly downward. Hence a transverse section of the stem which cuts through the different descending arms at different heights in their course, shows bundles of different structure and of various sizes.

This mode of growth and arrangement of tissue prevents any separation into pith and cortex, as is the case in the other two classes of the phanerogams. There is a subsequent thickening in the growth of the stems of monocotyledons, but it is entirely different from the annular depositions by which our perennial plants increase. A layer of the tissue which lies near the surface of the stem becomes changed in its character; new fibro-vascular bundles and intermediate

tissues form. These new bundles unite into a sort of net-work, which finally forms a kind of woody cylinder around the mass of tissues within.

A very remarkable plant among the monocotyledons is a water plant, the *Valisneria spiralis*. The curious phenomenon of cyclosis, the circulation of protoplasm in the interior of the cell, has already

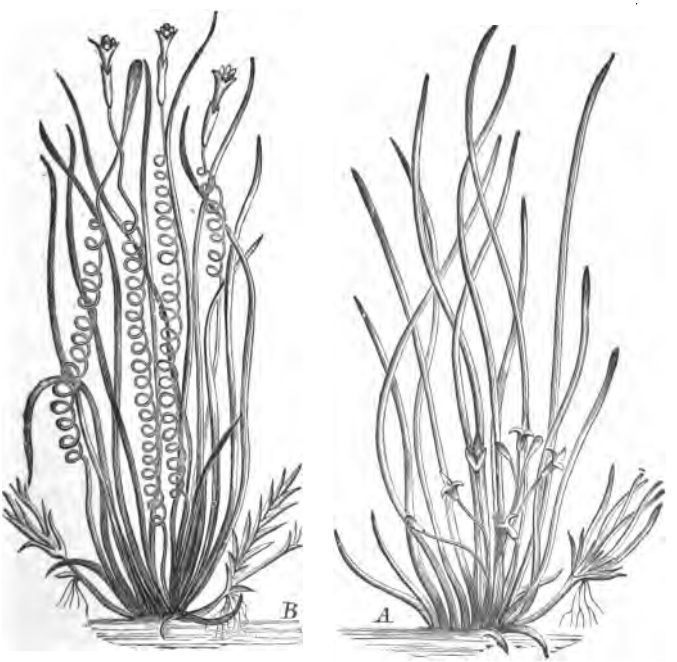


FIG. 43. VALISNERIA SPIRALIS
A, Male Plant; B, Female Plant.

been described in Chap. VI., on "the physiology of plants"; but this plant has other striking peculiarities in connection with reproduction [Fig. 43]. This is a diœcious plant, but the staminate, or male plant, A, always grows near the pistillate, or female, B. The latter, of which the essential portions may be seen in Fig. 44, is surrounded by a spathe [Fig. 44, F.], and it is borne at the end of a long, twisted peduncle, which springs from a tuft of radical leaves; it bears three forked stigmas, *b*, two of which *in situ* are exposed in F by the removal of part of the spathe. The male flowers [Fig. 43, A] are sessile, on a conical axis, also enveloped in a spathe; the flower [Fig. 44], *m*, is twice the natural size, its central spadix, *s*, is still more magnified, and at *c* may be seen a portion under a yet higher power of the microscope. At flowering time, the peduncle, on which the female flower grows, uncoils itself, so that the flower may float upon the surface of the water. The male flower, hitherto submerged, detaches itself from its stem and rises to the surface. A number of them may be seen surrounding the female flower, upon whose stigma their anthers elastically discharge an abundance of pollen. Corn represents a good type of wind-fertilized flowers; *Valisneria* of those fer-

tilized by spontaneous movement: both of which methods, however, are not very prevalent in the vegetable world.

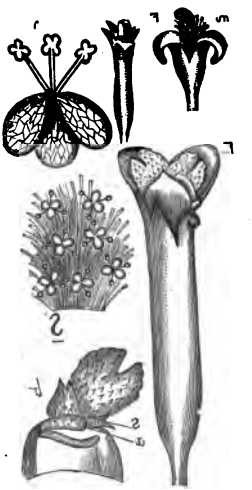


FIG. 44. VALISNERIA SPIRALIS. Male and female flowers enlarged.

The commonest and most perfect mode of fertilization is effected by the agency of insects. The contrivances which are found in various plants to lure the insects at the right time to the right place, are more than wonderful. The pollen is ripe and the ovules ready for fructification just when the flower has blossomed out, when the petals have on their most brilliant color, when the fragrance is most delicious, when the honey is most largely secreted. The nectarium lies deep in the heart of the flower, and the stamens and pistils are so arranged that in order to reach the honey the body of the insect must, in one position, brush the adhesive pollen grains out of the anther and collect them upon itself; and, in another, deposit them upon the viscid stigmatic surface. When cross fertilization is desir-

able, the modes of insuring this are many and marvellous.

There are no plants more wonderful in every way than the orchids. To begin with, they are epiphytes or air plants: growing attached to the branches of trees, or in pots full of sphagnum moss, they do not always declare their nature; but they are, most of them, true air plants, seeking from the bark to which they adhere, or the moss in which their roots are buried, only a foothold, and sometimes water, but no nourishment. It is among orchids, too, that we find the most wonderful contrivances for fertilization. It is found to be almost as commonly the case in the vegetable as in the animal world, that crossing the stock improves the quality as well as multiplies the varieties in the progeny. In Darwin's charming little volume upon the fertilization of orchids, multitudes of forms are represented, with an astounding number of variations of structure; ("contrivances," he calls them, though he ignores the Contriver,) to insure the cross fertilizations of these plants. Orchids seem especially to require this "crossing"; it goes so far that in some varieties the pollen of a flower is impotent where it falls upon its own pistil, and in one, at least, it acts as a poison. Among hundreds of

varieties described and figured by Mr. Darwin, only a few cases can be selected.

The orchid flower, to begin with, usually possesses three sepals and three petals, which form the corolla; one of the petals, which would be the uppermost one if it were not for a singular twist in the stem and ovary [Fig. 45, *s*] that brings it round so that it is really the lower part of the flower, is always modified in some curious way. This is really not a simple petal, but a complex organ, for it has incorporated into itself two of the stamens, and is called the labellum or lip, L. The other four stamens and three pistils have become confluent, and form what is called the column, including, of course, all the reproductive organs.

The stigma, or sticky portion of the pistil, and pollen occur upon most orchid flowers simultaneously, and the remarkable point in their economy is that so many wonderful contrivances are used to insure that the pollen of each flower shall not be deposited on its own stigma, but upon that of some other blossom of the same variety or species.

One of the simplest of these is *Orchis pyramidalis* [Fig. 45]. [A] represents a part of the flower from which the sepals and petals have been cut

away, with the exception of part of the labellum, L; *l* are the bases of the cut leaves, and *n* the nectary.

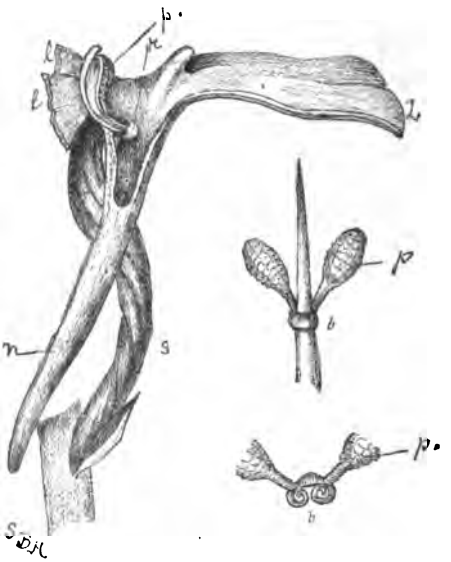


FIG. 45. DISSECTION OF ORCHIS PYRAMIDALIS.

r, Rostellum; *p*, pollinia; *l*, base of leaves cut away; *n*, nectary; *s*, stem L, labellum; *p*, pollinia clasping-needle; *b*, base of pollinia. [After Darwin.]

Looking carefully at the figure [45], a curved body, *p*, may be seen projecting into the upper portion of the nectary, ending in a cap, *r*, the rostellum. The body, *p*, instead of being an ordinary anther pod full of pollen, encloses the pollen, in another form; two small bodies with a common crescent-shaped

base, stand upright in the pollen cases; instead of loose pollen grains they cohere, being united by delicate elastic threads, and so with stalk and base form a double pollinium.

This orchid is visited by moths with long proboscides. The flower is brilliant in color, and has an attractive smell—characteristics of flowers which require insect agency for cross fertilization. A moth drawn to the flower by its color or odor would alight on the labellum, which seems as pefectly adapted to the purpose as the alighting board of a beehive; thrusting its proboscis into the tube to reach the honey, it touches the point *r*, in a second a little trap-door flies back, and the proboscis of the insect presses against the base of the pollinia *b*, just in the concave part of the base. The rostellum or base is covered with a sticky cement which "sets" hard in a very short time. When the moth withdraws its head the pollinia stand upright on the proboscis; in a few seconds more, by the curious mechanism of the plant, the crescent-shaped base closes tight around the proboscis. In this curving, of course, the two pollinia diverge from each other [Fig. 45, *b*, *b*]. The pollinia then make another movement; they slowly bend forward till they lie parallel with the proboscis.

Thus adorned, the moth, following the instinct of the insect tribe of not "mixing drinks," goes to another flower of the same kind. Now comes in the most singular part of the mechanism. As the insect enters, the two pollinia strike either side of the rostel-

FIG. 46. MASDEVALLIA BELLA.

lum directly upon the two stigmatic surfaces of the flower. The pollen masses are glued fast while the moth is emptying the nectary, and left behind when it flies away. If by any chance the insect leaves the

flower before this is fully effected, the elastic threads which bind the pollen masses together save them from being lost. The mode in which the moth's proboscis effects fertilization may be simulated by inserting a bristle into the nectary, leaving it there as long as it would take the moth to feed, and then inserting it into another flower. The pollinia come out of the first flower upright on the bristle, in a few seconds they diverge; when it is withdrawn from the second flower the stalk is found deprived of its pollen masses.

FIG. 47. CŒLOGYNE SCHILLERIANA.

Some remarkable forms of orchids are given in Figures 46, 47, and 48. The *Cycnoches egertonianum* is a most singular plant. It will produce for a long time flowers like those marked *v*, of a pale delicate green, and then suddenly bear an immense raceme of the flowers *e*, which are unlike them in form, color, and the number growing on one stem.

FIG. 48. CYCNOCHES VENTRICOSUM.
v. VENTRICOSUM ; *e*, EGERTONIANUM.

For some time the same plant, classified by its blossoms, received different names, *C. ventricosum*, and *C. egertonianum.*

Several orchids have been classified as different genera which after long study proved to be only the male, female, and hermaphrodite forms of the same plant: the flowers are so different that they were not even referred to the same genus.

The mimetic quality of the orchids has been greatly exaggerated by fanciful writers. Some of them, especially the columns of certain varieties, do look not unlike butterflies, and bees, and birds, but there is not one which could for a moment deceive the most unobservant. It is the oddity of the flowers, their curious suggestiveness of something abnormal, that really makes them such favorites, as well as the extreme rarity of certain varieties.

CHAPTER VIII.

THE MICROSCOPE AMONG THE FLOWERS.

DICOTYLEDONS (named because of the two seed leaves which first appear above the ground) are exogenous plants; that is, the cells which multiply and cause the growth of the plant lie just beneath the epidermis of the stem, or the bark. The members of this group, which live many years, are marked by annual rings of growth. The stem of any sapling or trunk of any tree sawed across shows this. Each year the growth of the preceding year loses its protoplasm; the cell walls turn into wood. Each year's growth forms a new ring; the loose open tissue being the summer's growth, the dense close tissue the winter's, and these two layers are the ring. Nothing is better known than that a tree which is girdled dies, and yet few people feel that all of the central woody part of a tree is really dead, and only the cambium layer just below the bark is living. This living layer adds to the wood by its yearly circles on one side, while it adds to the

bark by pushing in between the old cells new ones, and so enlarging its girth as the tree grows. Every dicotyledon, even the simple annual plants, show a wonderful differentiation of tissues in stems and roots. The conducting vessels, lactiferous vessels, glands, and so forth, are without number.

The main interest of this great class of plants, however, lies in the flowers and their modes of fertilization. The flower with its pistils and stamens, its petals and sepals about their floral axis, are usually arranged in concentric whorls, or in a close-coiled spiral, thus producing the rosette effect so characteristic of blossoms.

In many flowers the suppression of certain organs obscures the concentric arrangement of the petals. In some varieties one, and in some another, of the separate whorls may be absent, or reduced to a single representation, and in extreme cases the flower may be reduced to a single organ, staminate or pistillate. When the corolla consists of a single whorl of petals, they often cohere and form a bell-shaped flower. The pistils and stamens which occupy the centre of the rosette are merely leaves modified so as to fulfil their functions. Like the sporangia of the ferns, which are borne upon the under surfaces of

their fertile leaves, the pollen sacs of these higher plants are borne upon staminal leaves. There have been a few instances brought forward by Magnus, Kaufmann, and Rohebach, where this does not seem quite true, where, in fact, the pollen sac develops upon the end of the floral axis, but even here, it seems probable that the anther lobes are themselves abortive staminal leaves.

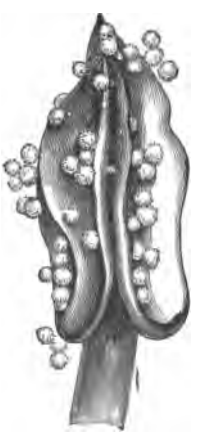


FIG. 49. ANTHER OF CYPRESS VINE WITH POLLEN.

The stamen generally consists of a long slender stem—the filament—which bears the anther upon its extremity. The anther is usually in the form of two lobes, springing side by side, either from the anterior or posterior side of a staminal leaf (never from both), each anther lobe being in its turn composed of two pollen sacs so closely adherent as to form a single lobe; in this case it is called quadrilocular; occasionally each anther lobe contains but one pollen sac, when it is bilocular. [See Fig. 49.]

The pistil, or more properly the gynœcium [Fig. 50], which contains all the pistillate portions of the

flower, consists of one or more closed chambers. The lower, hollow portion is called the ovary, the mass of tissue from which the ovules spring, the placenta. Above the ovary, the carpellary leaf or leaves which form its walls narrow into one or more stalk-like structures. The number of styles depends upon the number of carpellary leaves which form the walls of the ovary, each leaf sending up a separate style, though they are sometimes adherent through a part, and sometimes through the whole of their length. Upon the apex of each style is borne the stigma; this is usually a glandular swelling, excreting a viscid substance, which retains the pollen, and by its moisture induces the emission of the pollen tubes. The style is either a hollow tube, as in Figs. 50 and 51, or a mass of loose-celled tissue [Figs. 52 and 53] through which the pollen tube easily penetrates. The ovules [Fig. 50, *o*, *o*] are borne upon the margins of the carpellary leaves, or over their whole surface; with an occasional occurrence upon the floral axis, in which case the leaves are sterile.

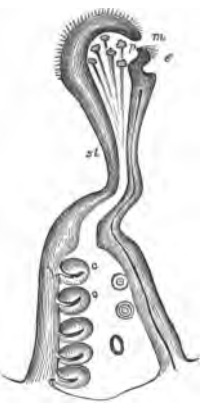


FIG. 50. SECTION THROUGH STIGMA, STYLE, AND OVARY OF PANSY.

st, Style; *o*, ovary; *p*, pollen grains sending tubes down style.

When the ovules of a plant are ready for fertilization, the stigma sends out a delicate papillæform growth, and excretes, upon its surface, a viscid substance. [Figs. 51, 52, 53.] The stamens either at the same time, or earlier or later, as the case may be, develop their pollen grains. The two lobes of the stamen then open, disclosing the mature pollen grains [Fig. 49] which are dispersed. The anther lobes open in various ways, generally, however, by the more violent contraction of one series of cells forming the anther walls, which causes rupture. But however the anther lobes may be opened,

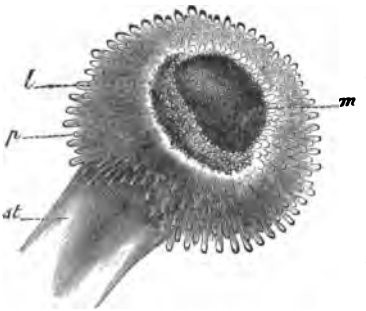


FIG. 51. STIGMA OF PANSY. [FROM NATURE.]

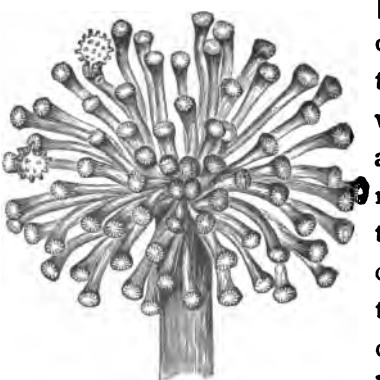


FIG. 52. PISTIL OF BUSH HONEYSUCKLE. [FROM NATURE.]

it is always intimately connected with the contrivances by which pollination is effected.

The pollen falls upon the stigmatic surface, is there held fast by the viscid secretion, and is made, by its moisture, to send out a pollen tube. Most pollen grains have definite places in their cellulose walls at which the tube is emitted. [Fig. 55.] More than one of these frequently begin to emit tubes at the same time, but only one reaches the ovule and fertilizes it. The ripe pollen grain, as we have already seen, is a single cell; it remains unicellular throughout its existence, the pollen tube is developed immediately upon the stigma, as a protuberance of the intine (or contents of the cell) which perforates the extine. When a pollen grain bursts in water, the contents escape often in long vermiform threads, which might seem to indicate some sort of modification of the cell contents with reference to fertilization. In some cases, as in Fig. 50, the pollen grains may be seen

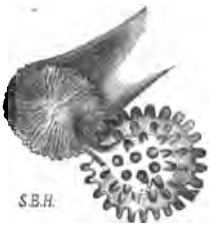


FIG. 53. POLLINATION OF BUSH HONEYSUCKLE. [FROM NATURE.]

FIG. 54. PART OF PISTIL AND POLLEN GRAIN OF CYPRESS VINE.

in the hollow of the stigma sending their tubes down the channel of the style; but more frequently they penetrate the loose cellular tissue, as in Figs. 52 and 53. The tubes increase by a process of true growth, which takes, in some cases, not more than twenty-four hours, but sometimes as long as several

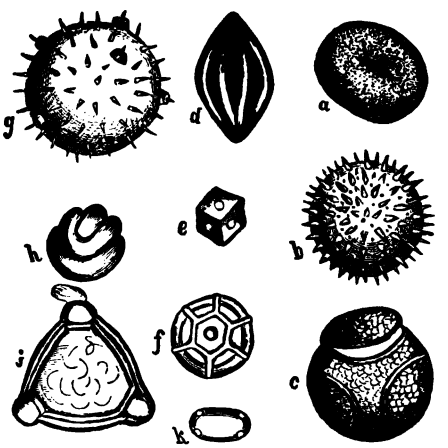


FIG. 55. POLLEN GRAINS.

g, Of *Cucurbito Pepo* [in water]; *d*, *Passiflora aquilegæfolia*; *a*, *Pelargonium speciosa*; *h*, *Mimulus moschatus*; *e*, *Basella alba*; *b*, *Hibiscus trionum*; *i*, *Epilobium montanum*; *f*, *Chicorum intybus*; *k*, *Impatiens noli me tangere*; *c*, *Passiflora cærulea*. [After Henfrey.]

months for completion. The ovules in many plants lie in such a position that the tube penetrates at once the micropyle, or opening into the ovule; in others it is guided by various contrivances to the

opening: papillose projections of the walls, tufts of trichomes, or even a funnel-shaped termination to the style itself effects the purpose. Every ovule in the ovary requires one pollen tube for its fertilization. A larger number of tubes usually enter the stigma than are needed, and in some of the orchids they may be detected with the naked eye, looking like a bunch of white silk threads depending from the stigma. The deposit of the pollen grain upon the stigmatic surface must be distinguished from the penetration of the ovule itself: the first is pollination [Fig. 53]; the second, fertilization [Fig. 56]. Pollen tubes are generally thin-walled and very slender while growing; after entering the micropyle, the wall thickens; the tube seems to be filled with granular protoplasm, generally mixed with starch grains.

The ovule [Fig. 56] is a rounded cellular mass, enclosed in one or two envelopes which grow up and around the nucleus from its base [B], and form—at its apex [A], where they greatly overtop it—a canal-like opening [A], called the micropyle. Through this channel the pollen tube [P] enters, reaches the embryo sac, *e*, and fertilizes it. The embryo sac itself results from the enlargement of one of the inner cells of the nucleus. *After* pollination takes place,

but *before* the ovule has been reached by the tube, immediate change takes place in the flower, especially in the pistillate portions: the stigma, style, and even the corolla wither, and the ovary enlarges. The changes which occur when fertilization takes place are even more striking, the ovary in some plants increasing to several thousand times its original volume. In some of the orchids, where the progress of pollination is very slow, the ovules are never developed at all until the grains send out their tubes, and their formation appears to be a direct consequence of pollination.

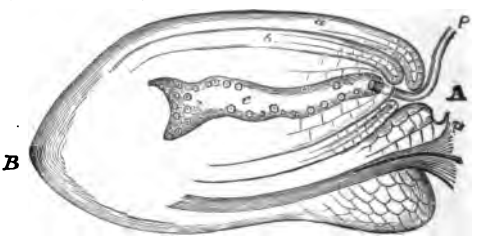


FIG. 56. OVULE BEING FERTILIZED.

B, Base; A, apex; P, pollen tube entering *e*, embryo sac; *a* and *b*, envelopes; *f*, placenta. [After Sachs.]

In the lower forms of this group the flowers are typically unisexual; in the higher, hermaphrodite, "although monœcious and diœcious families and genera are not uncommon." The forms of the staminate and pistillate portions of various plants, and

the processes of pollination and fertilization, are so different, as well as the means by which they are effected, that the simpler way will be to illustrate each by characteristic examples.

Pollination—so the best authorities tell us, in contradiction of the popular belief—is rarely effected by the wind alone. Where this agency is used, as in Indian corn, for the conveyance of pollen from anther to stigma, there is an enormous development of pollen; and it is also found that no honey is secreted by wind-fertilized flowers, and that their pollen grains are dry. The spontaneous movements of flowers, already alluded to, have generally a very close connection with pollination. Rue is a remarkable instance of this: the flower has four or five petals and eight or ten stamens (so Le Maout tells us); one stamen, instead of spreading horizontally over one, or between two petals, which would seem to be the normal position, bends over the pistil. If watched patiently, the anther will be seen to burst open, to emit its pollen upon the stigma, and, having fulfilled its function, to fall back; another stamen then rises, sheds its pollen and retires, and so on, till every stamen has discharged its pollen upon the stigma, and thus insured the fertilization of all the ovules.

The commonest of these contrivances is called dichogamy, which, being interpreted, means merely that the pollen and ovules reach maturity at different periods, so that self-fertilization is impossible; in some cases the anther, in others the stigma, is developed first. Another common method for insuring cross fertilization is the relative position of stamens and pistils, which makes it almost impossible that the pollen of a certain flower should fall upon its own stigma. A third method is the impotence of the pollen of certain plants when placed upon their own stigmas. The fourth and last is dimorphism, or a different relative development of the reproductive organs in different flowers of the same species. This is very well illustrated by the flax and the English primrose. In the flax the stamens and pistils are so placed that an insect entering a flower in quest of honey cannot fail to load itself with pollen, which it deposits upon the next flower visited. The well-known habit of insects—especially bees—of visiting only one kind of flower on each excursion, aids greatly in disseminating pollen where it will fructify. The pollen of a flax blossom, when artificially placed upon its own stigma, fails to fertilize, though it is potent on other flowers precisely similar.

Darwin found two varieties of blossoms on the primroses, which he has observed with that exquisite minuteness and accuracy characteristic of all his

FIG. 57. ANTHER OF PANSY WITH ADHERENT POLLEN GRAINS. [FROM NATURE.]

naturalizing. One of these flowers possesses long styles and short filaments, the other long filaments

and short styles, so situated that cross-fertilization by insect agency is secured. The pollen of the same flower, however, in this case, is capable of fertilizing its own ovules, though fewer and less perfect seeds were found to be the result of self- than of cross-fertilization. In connection with these facts, it is very curious to note that there are a number of plants among the higher genera which develop two kinds of flowers, the one for cross-, the other for self-fertilization. In the sweet violet, for instance, the ordinary flowers are often infertile, while there are small inconspicuous flowers near the ground which never open, the pollen tubes of whose anthers, without leaving the lobes in which they have developed, penetrate and fertilize the ovules: all this takes place within the corolla.

The *Viola tricolor*, our common pansy, or heart's-ease, is beautifully contrived to insure cross-fertilization. Many a sweet bright morning I have spent in trying to penetrate the mysteries of the fertilization of our common garden flowers. The pistil [Fig. 51], anther [Fig. 57], and ovary [Fig. 58], were taken from the same pansy. It was difficult, in dissecting the flower, to understand from the position of the different organs how pollen developed in the anthers

which were wrapped about the ovary down in the heart of the flower could reach the stigma so far above. Though I was quite familiar with all the

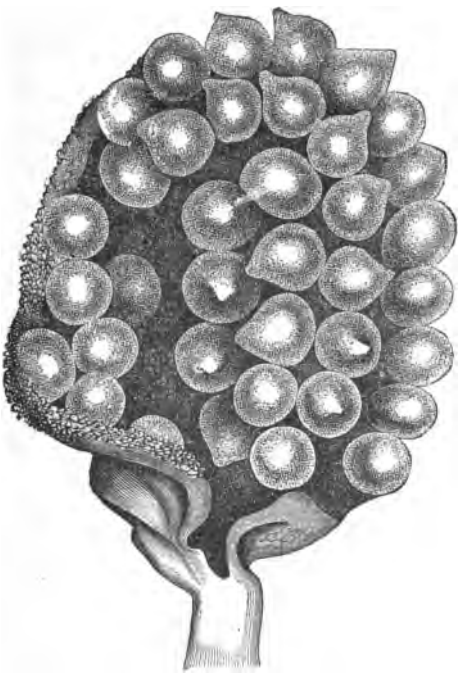


FIG. 58. SECTION OF OVARY OF PANSY. [FROM NATURE.]

wonders of the orchids, for some reason, cross-fertilization by insect agency did not suggest itself. Pansy after pansy was devoted to dissection, but all

told the same story, that at last found its explanation in Sachs' wonderful "Handbuch," which seems to have every thing in it, and which certainly answered every one of the thousand questions raised during the many hours of close examination given to the subject some summers ago. The cavity of the corolla is filled by the anthers, with the exception of a narrow space which leads to the nectaries. As the insect enters, it is forced to pass close to the open, hollow, and lipped stigma, which may be seen in section in Fig. 50; in extracting the honey, it is closely pressed against the anthers, and becomes covered with the pollen dust. As it retreats, the lower lip of the stigma guards its entrance from a deposit of pollen. The next flower entered, however, receives the pollen collected in the previous one, for the lip which guarded the stigma against the reception of its own pollen as the insect backed out of the flower, scrapes it off and throws it inside the hollow as it enters the new one.

One of the most remarkable instances is found in the *Aristolochia clematitis*,—the Dutchman's pipe of the vernacular. [See Fig. 59, A.] The stigma, *s*, ripens first, the flower is then in its full beauty and the honey is plentiful; for the sake of brevity, we

will suppose an insect which comes to it loaded with pollen from another blossom of the same plant. It enters the flower by the calla-like mouth (this representation, it must be remembered, is much smaller than natural size), the throat is lined with a quantity of vegetable hairs inclining downward. These yield readily under the weight of the insect, but when it reaches the cavity about the reproductive organs and has satisfied itself with honey, an exit is found to be impossible; the inclined hairs which yielded so gracefully as the prisoner entered offer an impossible *chevaux de frise* to his departure. In wandering about his prison-house our little captive comes in contact with the viscid stigmatic surface, and deposits upon it the pollen with which it was loaded. As soon as pollination takes place the stamen starts up—the anther opens and discloses the pollen. The captive takes on another load, and lo! his prison bars have melted away and he is free. The tiny

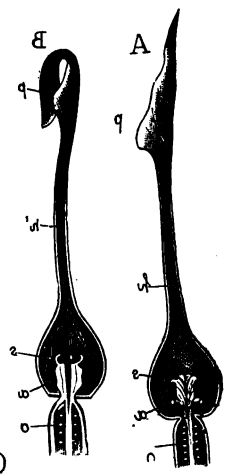


FIG. 59. ARISTOLOCHIA CLEMATITIS. [AFTER SACHS.]

hairs have withered away to their roots and the passage is clear. After his escape the leaf of the flower drops over the throat, and the door is shut against future visitors. Sometimes six or seven insects may be found shut up in the cavity of a single flower, but they are all released after they have done their work and received their wages.

FIG. 60. PISTIL OF FISH GERANIUM.
s, Stigma; *a*. *a*, crimson points from which the anthers had disappeared; *h*, hairs. [From Nature.]

The ordinary scarlet geranium—the fish geranium, as it is generally called—is a good illustration of dichogamy. On dissecting a multitude of the flowers which grew in the open air, and subjecting them to microscopic scrutiny, not a single anther could be found. The pistil [Fig. 60] stood up like a lovely rosy lily springing from a pale emerald base tipped

with carmine, but where were the anthers? At last, in laying open younger and younger flowers, the anthers were found sessile upon the crimson points, *a*, *a*: they are so like the stamens of the cypress vine in form that it did not seem worth while to draw them. [See Fig. 49.] When the first flower

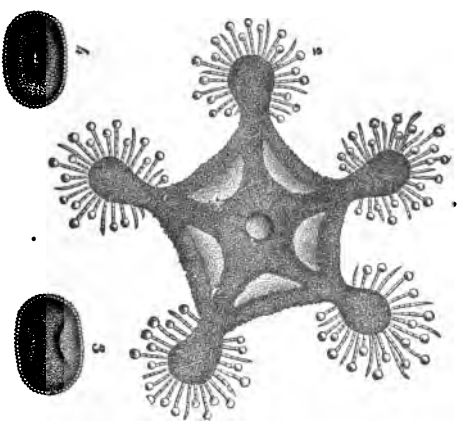


FIG. 61. CROSS-SECTION OF OVARY OF FISH GERANIUM.
1, 2, Hairs; 3, pollen grain; 4, same in another position. [From Nature.]

opens, the curving leaves of the lily-like pistil are all curled in; the pollen which is ripe is then conveyed away by insects, and when all probability of self-fertilization is over, the pistil unfolds to receive the pollen of some younger flower. A cross-section of the ovary, with ovules yet undeveloped, [Fig. 61], gives no idea of its beauty as seen under the glass.

So far, only the fertilizing power of the pollen of one flower upon the stigma of another of its own variety has been alluded to. There are many instances, however, where a hybrid is produced by the fertilization of one variety, species, or—even in rare and exceptional cases—genus, by the pollen of another. Many beautiful variations in cultivated plants have been produced in this way. The degree of affinity which permits hybridization is known as a matter of fact, though the theory is yet very imperfect; and without further knowledge no predictions can be made, and each phenomenon must be observed for itself. Many curious and anomalous facts have been observed in this connection. Professor Asa Gray gives a case in which an apple was found which was half Spitzenberg and half russet. It was produced upon a Spitzenberg tree, though a russet grew not two hundred yards off.

This whole subject is, in fact, full of a beauty which is indescribable. There is nothing more exquisite in all microscopy than flowers,—especially the pistillate and staminate portions of them. The coloring and texture are so exquisite that it seems almost a pity to try to represent them in black and white. The stamen of the common cypress vine, for

instance, which is given, as far as mere form is concerned, in Fig 49, looks under a moderate power like a delicate shell, carved out of a single ruby, in which are nestling treasures of shimmering pearls of the purest white. An enthusiastic admirer looking at it, said: "This gives one a new idea of Venus rising out of her jewelled shell"; and, indeed, the beauty of form and color demands analogies which are always rejected in the end as unworthy.

CHAPTER IX.

THE PITCHER PLANTS.

THERE are, besides the fungi, a number of plants which seem flatly to deny all the traditions of vegetable life; which do not live solely by the conversion, within their tissues, of the inorganic elements of earth, and air, and water, into organic matter; but which depend, in some measure, for their sustenance, on matter already organized. The distinction generally made by naturalists between the two great kingdoms of organic nature, as we have already seen, is, that while vegetables transmute inorganic, or mineral, substances into organic, or those which possess the power of growth and reproduction, animals only reconvert the matter thus transmuted into new organisms. Though this is in a general sense true, yet it does not express the whole truth. Vegetables have, as we very well know, the power of appropriating for their support the results of organic life. The soil in which they grow, and from which they derive their nutriment, is

largely made up of the decayed vegetation of a previous growth, and even of decomposing animal matter; while, on the other hand, animals are abso-

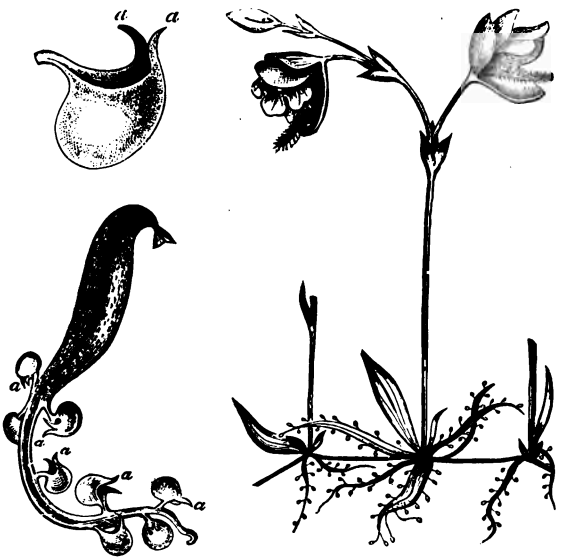


FIG. 62. UTRICULARIA JAMISONIANA.

A, Plant (natural size); B, leaf bearing utricles (10 diams.); C, single utricle (40 diams.); *a*, *a*, antennæ. [After Oliver.]

lutely dependent for existence upon two elements belonging to the realm of inorganic nature,—air and water.

The plants to which reference is now made, have, however, a power of appropriating organized material

and living upon it, which is altogether different from any thing common to vegetable life. The name carnivorous, or insectivorous, plants, is given to them all alike; but it is possible to arrange them into a series which shall represent the gradual divergence from the ordinary vegetable mode of nutrition, till that peculiar to animal life is very nearly approached. This series has nothing whatever to do with botanical classification, but is merely made with reference to organic and functional development. The insectivorous plants may be, for convenience' sake classified as of two kinds: those which really digest and assimilate food; and those that secure their prey within some leafy structure, retain it till it is decomposed (a process frequently hastened by some secretion of the organ), and then absorb the liquid compost. This latter class is best represented by our American pitcher plant; and as its mode of nutrition is most like that of ordinary plant-life, it comes first in our series.

In the study of nature, thousands of facts present themselves which must be accepted, and which have yet received no explanation: but besides and beyond this, there is constantly found some subtle link which binds these facts together without appar-

ent reason, so that a development in one direction is invariably accompanied by a correlative development in another; though why this should be, no one has ever been able to guess. The invariability of these relations in anatomical structure enabled Richard Owen to describe, from a single bone, an animal so utterly dissimilar to any living creature that even Murchison, one of the best geologists of his time, entreated him not to give the description of such an anomaly to the public. But Owen's knowledge of comparative anatomy was a sure guide, and did not lead him astray, for a living representative of the mighty *Dinornis* of geologic times was subsequently found, which proved the truth of his conclusions.

This simultaneous development in different directions from the original form, or correlation, it is, which gives the fixity of relation that enables the naturalist to work in his peculiar field of inquiry. It is the inflexibility of physical laws which alone enables man to use them in order to the carrying out of his purposes; it is the perfect certainty with which he can count upon their action which alone enables him to calculate results; it is the cleft in the rock and not the moving desert-sand that gives foothold to vigorous and unspringing life.

One of these singular correlations for which we can see no possible reason, is the contemporaneous development in plants of the true root and the fibro-vascular bundles of their stems. As the whole aërial portion of the plant becomes more highly organized, the subterranean portion also changes its character. In accommodation with this correlation we find that it is by means of special organs, per-

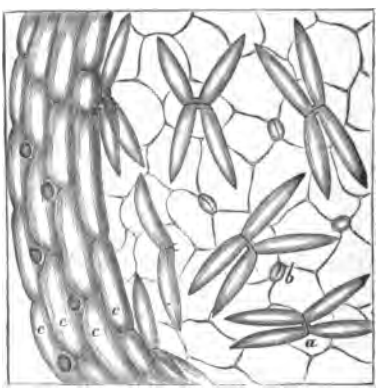


FIG 63. CELLULAR SURFACE OF UTRICULARIA VULGARIS.
a, Quadrifid processes; *b*, glands; *c*, *c*, cells of the walls of utricle with glands. [From Nature.]

forming the functions of roots, that plants are lifted one degree higher in the scale of being,—that they approach one step nearer to animal life. Before coming to our main subject,—the American pitcher

plants,—there are a few very curious forms which are needed to complete the chain extending from vegetable to animal life, in regard to their modes of assimilation, and so binding organic nature into one perfect and harmonious whole. These illustrate the gradual modifications of structure by which true plants gaining their nitrogen by means of roots are bound into unity with animals gaining theirs by means of a process of digestion.

A hasty recapitulation of a few points is here essential, and will be pardoned. In ordinary plant life among the higher organisms, roots assimilate by extending themselves underground and sending out upon their branches multitudes of delicate fibrillæ, or root-hairs, which come into direct contact with the moistened particles of earth around them. The water which adheres to these minute particles of soil, Sachs tells us, is directly continuous with the cell sap of the roots. There is in vegetation a continual loss of water in consequence of evaporation and of the vital processes of the plants, and this must be made good by an equal absorption of moisture by the roots. Not only is the necessary water thus supplied to the organism, but also such matter as the water holds in solution. But there

are many substances present in the soil in an undissolved condition which are yet necessary to the plant. The tiny root-hairs, by their innumerable ramifications, come into contact with multitudes of particles of earth containing chemicals in the condition called "fixed." Though insoluble in water, these substances are dissolved by the carbonic acid exhaled by the roots and thus rendered fit for appropriation by the plant. The largest element in atmospheric air is nitrogen; and though it is essential to the life of vegetation, plants possess, singularly enough, no power of assimilating the free nitrogen of the air, as they do its oxygen and carbonic acid. This essential element must therefore be secured by some other means. In the higher plants it is taken up from the soil by means of their roots, where it exists in chemical combination with other substances. The insectivorous plants, which possess very minute roots,

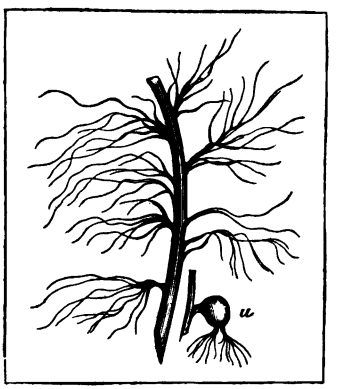
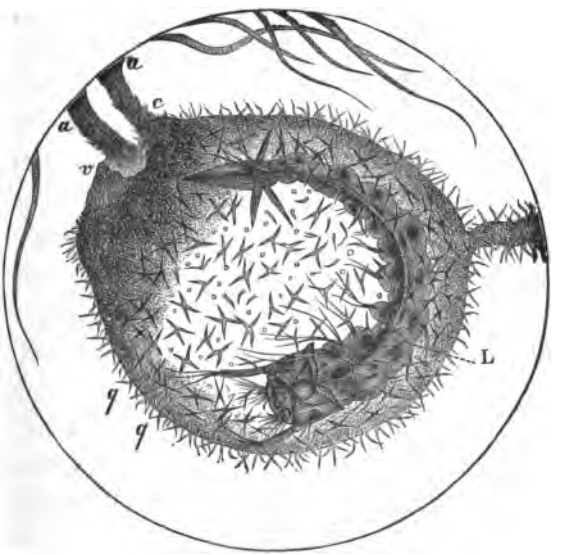


FIG. 64. UTRICULARIA VULGARIS (5 DIAMS.). *u*, Utricle (10 diams.). [From Nature.]

it will be seen, have an independent and novel mode of supplying themselves with the necessary nitrogen. They secure it in various ways; but in each case by means of some organ specially adapted to the needs and circumstances of the species upon which it is found.



65. UTRICLE WITH CAPTURED PREY.

v, Valve; *c*, collar; *a*, *a*, antennæ; *q*, quadrifid processes; L, chironomous larva. [From Nature.]

The insectivorous plant which most nearly resembles in its mode of nutrition ordinary plants, is

an insignificant little epiphyte found in tropical South America. It is generally grown as an air-plant; though it has been successfully cultivated in greenhouses in a very moist and peaty soil. Instead of roots the *Utricularia montana* produces colorless, thread-like rhizomes (creeping underground stems) which sometimes swell into tubers, and which bear upon them minute bladders or utricles of a very singular character. When grown in the soil, the rhizomes, with their bladders, penetrate it to the depth of two or more inches; but in its natural state as an epiphyte, they must creep in among the decayed bark and thick moss which cover the trees in the tropical forests of South America. Darwin mentions that some of the plants in his possession bore several hundred utricles. The bladders are, in form, compressed and rounded. The antennæ, as Darwin calls them, instead of spreading out and leaving a large opening to the cup-shaped utricle, as in *U. Jamisoniana* [Fig. 62, B, C], which is also an air-plant, curve around and downward on each side of the opening (or upward when the position of the utricle is reversed), thus guarding the entrance from being choked up by earth or decaying vegetation. The utricles are colorless and transparent, and meas-

ure only about $\frac{1}{20}$ of an inch in diameter. Their walls are formed of two layers of cells of an angular shape, at whose junction small papillæ project. The entrance to the bladder is guarded by two prolongations of the cellular walls which dip sharply down into its cavity and form a perfectly fitting valve. [Fig. 65.] Of these two prolongations, the one nearest the stem, called the collar or peristome, is thick, stiff, and almost semicircular; against this the valve, which is thinner and more flexible, directly abuts.

Within the bladder and scattered along the borders of the valve are the organs which supply to the plant its necessary nitrogenous food. These are minute glands not more than $\frac{8}{4000}$ of an inch long, and a "serried mass of processes," called by Darwin, bifid, trifid, or quadrifid processes, according to the number of arms they possess. Each one of these consists of several divergent arms, generally four, mounted upon a short pedicel. A glance at Fig. 63, which shows the like processes in *U. vulgaris*, will give an idea of their form and appearance, though in *U. montana* the arms lie side by side in pairs, more closely, and they differ somewhat in length. A number of experiments made by Darwin proved that,

whether these glands and processes possess the power of secretion or not, they certainly absorb organic matter from their captured prey. The observations of Mr. Darwin, and the earlier ones of Mrs. Treat, left it doubtful whether the minute animals which found their way into the bladders merely forced their way in through the valve, or whether the valve possessed some power of movement which captured them against their will. Darwin evidently inclines toward the former opinion, though he gives some experiments which point to the latter; but Mrs. Treat's observations, made and recorded since the publication of Darwin's book, seem to prove conclusively that these tiny vegetable bladders open their valves and snap up their unwary prey. In the figure of *Utricularia Jamisoniana*, drawn after Professor Oliver, no collar or valve is to be seen, though from the scale upon which it is drawn, as well as the manner in which it is delineated, they would probably be imperceptible. The figure is given, however, without reference to the functions of the bladders; but in order to show that the utricles, which occupy the position and perform the functions of roots, are yet, in reality, modifications of the foliage leaves. In this whole group (speaking of them generally and

not scientifically, as belonging to one group), the organs which appropriate formed matter for the sustenance of the plant are modified leaves; and these, where there is sufficient approximation to the possession of a root to determine the matter, are, with a few exceptions, all radical leaves.

Most of the *Utricularias* are rootless aquatic plants which float about in the water; upon the submerged portion the utricles are borne; these utricles first received the name of bladders because it was supposed that they served the purpose of sustaining the plant in the water. From this plant (part of which may be seen in Fig. 64), at certain seasons, springs an aërial axis, bearing delicate flowers, very like some of the orchids. A writer in the *Annales des Sciences Naturelles* says with reference to one of these curious plants: "Each of these beings [the aërial and aquatic portion of the same plant] not only accomplishes a special function in a particular mode, but each possesses an intimate structure appropriate to this function, and to this mode; and the difference in this regard is so great between the two, that where any anatomist has isolated fragments of the two axes submitted to him, he does not hesitate to assign them to distinct and widely separated "vegetable types."

The *Utricularias* are the only family of those carnivorous plants that absorb decomposed matter rather than digest animal food, which have been carefully studied with reference to their functional peculiarities. The anatomy of the pitcher plants is very well known, but their physiology has yet to be learned. Darwin has subjected the glands and quadrifid processes of the utricles in this group of plants to the closest scrutiny; he has looked at them with an eye trained by a long study of other plants allied to them by their mode of life, and has shown that the glands do absorb organic matter which becomes changed within its tissues into protoplasm. The contrivances and cellular structure of our various pitcher plants leave no doubt that their mode of absorption is similar, but it is inference rather than observation upon which we have to depend in this matter.

In 1815, Dr. McBride, a physician of South Carolina, devoted some attention to a species of very remarkable plants which grew in a marsh near his residence: this was the *Sarracenia variolaris*, popularly called the American pitcher plant or side-saddle flower. A cluster of leaves spring from the ground: some of these are ordinary foliage leaves, while the

others have enormously developed petioles, which, curving around laterally and becoming adherent throughout their whole length, form a trumpet- or pitcher-shaped vessel, above which the leaf proper is developed.

The *Heliamphora* [Fig. 66], and the *Sarracenia*

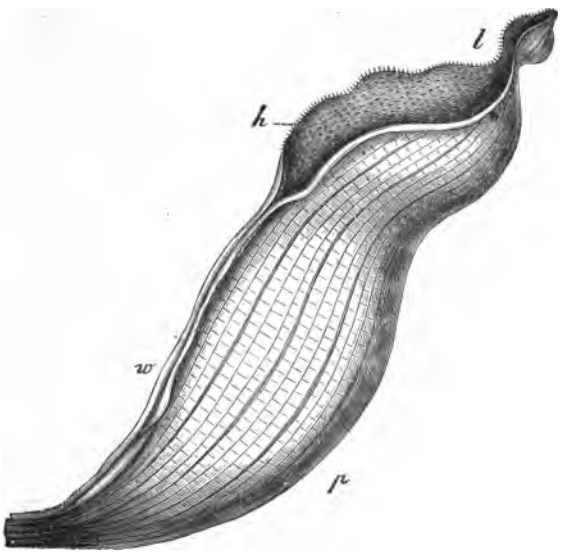


FIG. 66. HELIAMPHORA.
p, Petiole doubled to form pitcher; *l*, leaf, rudimentary lid; *w*, wing, formed by non-adherent edges of petiole. [After Bentham.]

purpurea [Fig. 67], show this with perfect clearness. *S. variolaris* has a curved lid, formed by the bending

of the leaf around and over into a dome-like roof to the pitcher [Fig. 68]. There are many known

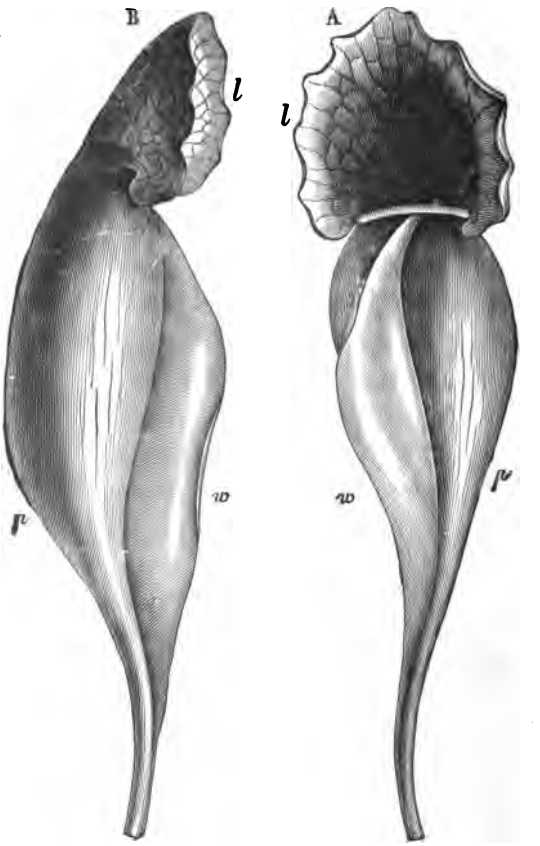


FIG. 67. SARRACENIA PURPUREA.

A, Front; B, side view; *p*, petiole; *w*, wing; *l*, leaf forming lid. [From Nature.]

species of the *Sarracenia* family, which do not differ very greatly from each other; but as *S. variolaris* has been most closely studied, it will be best to confine ourselves to that, in order to illustrate the structure. In favorable situations, with plenty of air, moisture, and sunshine, these plants spring up in great clusters, their trumpet-shaped leaves growing from a foot to eighteen inches in height. The lid or hood, as well as a portion of the pitcher down the back, or part adjacent to the midrib, *a*, *a*, is curiously marked with white translucent spots, *s*; between these may be seen green or red reticulations, *r*. About the mouth, *m*, over the inner surface of the hood, *h*, and down the outer edge of the wing, there are seated glands which secrete honey [Fig. 69]. Hooker, in describing the inner

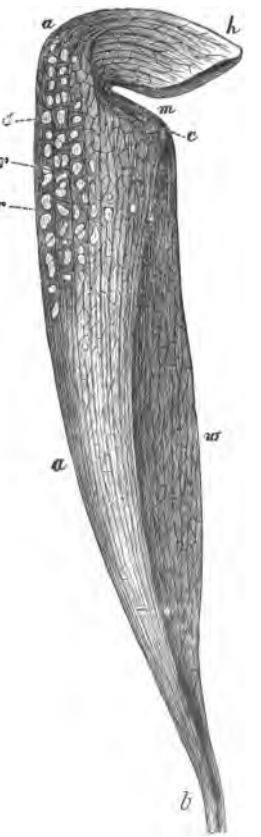


FIG. 68. SARRACENIA VARIOLARIS. *m*, Mouth; *w*, wing; *h*, hood or lid formed by leaf; *a*, petiole forming pitcher; *c*, cord; *r*, *r*, reticulations; *s*, dianhanous spots; *b*, stem. [From Nature.]

surface of the tube, divides it into four portions. The spotted and reticulated portion, including the hood and pitcher for about an inch below the cord, *c*, he calls the attractive surface; it is covered with hairs, and possesses some breathing pores and many honey-secreting glands [Fig. 69]. The second surface, just below this, he calls the conductive surface; it is

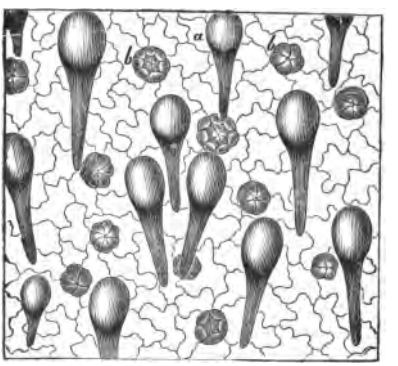


FIG. 69.

Hairs *a* and honey glands *b* just inside of mouth of pitcher; the different cell arrangements of the honey glands represent different layers of glands seen at a different focus of the glass.

formed of glassy cells elongated into short conical processes which overlap each other like shingles upon a roof, and forms a very insecure foothold for insects. [Figs. 70, 72.] The third or glandular surface is also very insecure ground, and is covered with glands;

this occupies a large portion of the tube. At the bottom is the fourth or detentive surface, formed of curiously-shaped cells, whose surface wall is every now and then drawn out into an enormously elongated sac, forming the detentive hairs [Fig. 71.]

In April, the plants bloom freely, the pitchers are still tender and immature, and their lids are quite

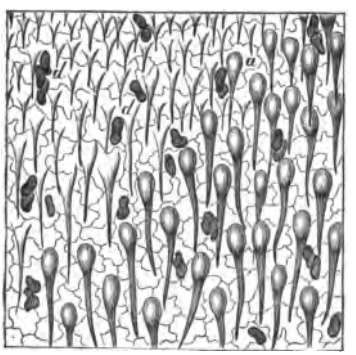


FIG. 70.

Development of detentive hairs on lower part of pitcher *S. variolaris*: *d*, *d*, cells especially colored owing to some unknown peculiarity. [From Nature.]

closed. Dr. Mellichamp—to whom we owe most of our information in regard to this species—examined many pitchers which had not yet lifted their lids, and into which no moisture could have penetrated. He found in each a small amount of fluid which was sticky and somewhat astringent, closely resembling

the taste of the roots whose functions the tubes help to fulfil. No remains of insects were found in the unopened pitchers, but in the old ones, a mass of insect remains filled the small end of the tube to the height sometimes of six inches. In 1874, Dr. Mellichamp made a number of close observations on the *Sarracenia* leaves [Fig. 68]; he found that the secretion of honey—up the front of the wing, *w*, from the ground — formed a trail along which ants and other small creatures crawled. On reaching the mouth, *m*, they crawled over the cord, *c*, into the tube itself. There seems to be

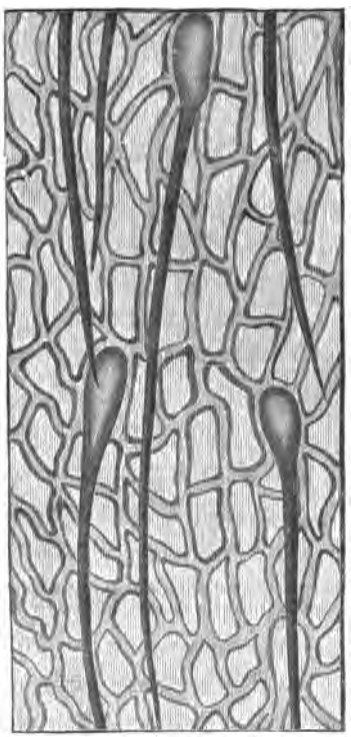


FIG. 71. SARRACENIA VARIOLARIS.
Full-grown hairs on detentive surface (250 diams.). [From Nature.]

some question as to the nature of the secretions. Dr. Mellichamp's observations led him to think that there was no intoxicating property either in the fumes of the secretion or in the honey itself.

To test this point, insects were suspended by him in a gauze net above the liquor which fills the tube below; they were also allowed to feed freely upon the honey outside the pitcher, and in neither case was any peculiar effect observed. Mrs. Treat, however, in some late investigations made upon

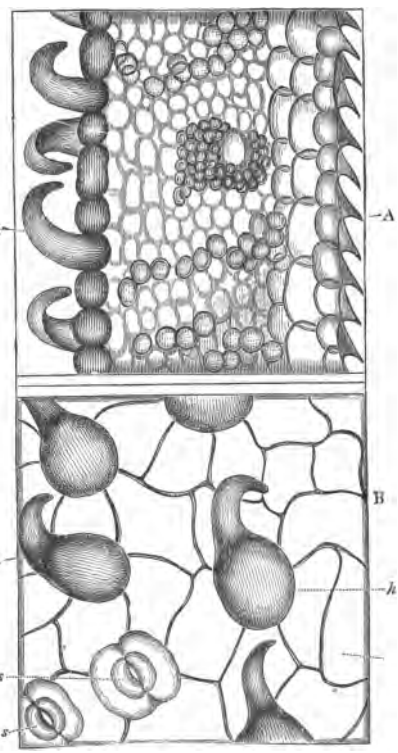


FIG. 72.

A, *S. Variolaris*, vertical section of hood; *h*, hairs of external portion; *a*, conical downward-pointing processes on internal surface, like those on conductive surface (100 diams.); B, same tissue, seen from above; *h*, hairs; *s*, stomata (250 diams.). [From Nature.]

these plants, considers the honeyed secretion to be intoxicating. When an insect,—a fly, for instanec,—which walks with such ease and security upon the smoothest surface, enters the tube, he slips and tumbles about in the most drunken way; this, Professor Riley says, is due, not to the intoxicating fumes of the liquor, or the effects of the honey, but to the nature of the pubescence upon which he has to walk. Just below the entrance, as has been said, are the delicate, overlapping, downward-pointing processes of the conductive surface. Flies walk upon smooth surfaces by means of a very complicated apparatus; the popular idea of each foot possessing a sucker is long ago exploded. Upon a surface presenting slight roughness, the foot clings by means of claws; on perfectly smooth surfaces, by means of a slight viscious secretion, probably aided by atmospheric pressure. The surface of the conducting portion in the *Sarracenia* tube affords neither a smooth surface for the use of these pulvilli, nor one so formed as to admit of the claws taking hold. The delicate, downward-pointing hairs give under the weight of the insect. Even when the tube is laid horizontally the insect is seen continually to slip backward; and this effect would, of course, be much more marked if the tube were erect.

An insect which has once entered the fatal trap finds escape impossible; he slips on the glassy pubescence, and struggles to regain foothold, each effort only sending him farther into the abyss. Finally he is plunged into the pool below, and soon becomes insensible from its anæsthetic quality. The white translucent spots, *s*, appear to serve a purpose in this marvellous trap. The mouth of the pitcher is so completely overhung by the arched lid, that an insect once fairly in the tube cannot possibly see any opening above it, and would naturally direct its flight toward the shining white spots in hopes of escape; in this case it would, of course, fall back after striking these skylights,—as helpless as before, and often hopelessly lost. This is not a mere matter of conjecture; it is an observed fact, that flies are seen continually striking against these diaphanous spots, in their struggles to escape from the snare in which they had been caught.

There are, however, several insects which live, in safety, within this miniature charnel-house. These are each supplied with some peculiar, though not exceptional, form of structure which enables them to brave the dangers of the pit. One of them, the *Xanthoptera semicrocea*, a beautiful and glossy moth, pos-

sesses upon its feet very long spines which penetrate the pubescence, and take firm hold upon the cellular surface below; the female deposits the eggs late in April, and when the larva hatches, it spins a delicate web over the surface of the hairs which enables it to move securely about. Then the larva begins to "nip" a little at the inner surface of the pitcher; and when it grows older and stronger it spins a web securely across the opening of the tube. Our larva having defined the limits of his preserve, sets himself to the work of retaliation in earnest, eating away the leaf till only the outer epidermal layer of cells is left. In small leaves, almost the whole tube is thus destroyed; but in larger ones only the upper third, which contains the honey glands, is devoured. The pitchers look blasted and burnt, the upper portions of the leaves generally collapsing and falling down, after the work of the larva is done, the lower portions being held in place by the mass of packed insect remains that fill them.

The *Sarracenia purpurea* [Fig. 67], which is found in many parts of our country, and as far north as Canada, Hooker thinks, has no especial secretion of its own, or at all events does not secrete until it has been partially filled with rain. The upper portion is

not guarded, as many others of the *Sarracenias* are, from the entrance of rain-water [Fig. 67]; the hood, or leaf, as may be seen, stands at such an angle as to admit it freely. It possesses three instead of four surfaces, and is the only one of the family which has an especial glandular surface.

There is an obscure species of pitcher plant found only in British Guiana and in the Roruma Mountains of Venezuela, at the height of six thousand feet above the level of the sea. Whether it is an insectivorous plant or not has not been determined; but it has a value as one of this family, in that it supplies to the eye an unanswerable argument in favor of the accepted theory in regard to the development of the pitcher. We are told by the botanists that these tubes are modified petioles, or leaf-stalks, while their lids are the modified leaves. A glance at the *Heliamphora* [Fig. 66] shows this to be the case. The broad petiole curves around and meets, and becomes adherent at a line a little within the lateral edges, allowing them to fold back. That which in the more perfect pitchers of the *Darlingtonia* and *Sarracenia* would otherwise be difficult of comprehension, is thus made clear by a single look at the intermediate form. The turned-back edges of the leaf represent the wing,

which in some species is single,—in other words, the edges of the leaf are adherent throughout, and in others are separated in some portion. The hood finds its representation in the curious little curved leaf which crowns the tube. The presence of an internal pubescence affords a strong presumption in favor of its being insectivorous.

The last of this singular family of plants which will be noticed is the *Darlingtonia Californica*, called, as the *Heliamphora* might also be termed, "an insignificant geographical outlier" of the *Sarraceniaceæ;* for it is found only in the boggy morasses close under Mount Shasta,—one of the peaks of the Sierra Nevada,—and at a height of from five to seven thousand feet above the level of the sea. This is the most beautiful, both in form and color, of the pitcher plants. It rises, as they all do, out of the soil, as a cluster of radical leaves, from the midst of which spring the flower-bearing stems, with their nodding scapes. [Fig. 73.] It is cultivated with the utmost difficulty. A few years ago there was a fine specimen in the greenhouses of the Agricultural Department in Washington, from which the leaf showing the glandular surfaces [Fig. 74] was taken; but it died long ago.

From the figure it will be seen, that while the *Darlingtonia* tubes present some resemblances to those of the *Sarracenias*, they also present differences. In every description and figure of the plant which I have been able to find, all the leaves are pitcher-shaped; as is also the case with certain varieties in the *Sarraceniaceæ*. Each tube is twisted upon its axis about half a turn. All the leaves upon a single plant twist in the same direction, but some plants show a uniform twist to the right, and others to the left. The arched lid, instead of being formed of the leaf, as is the case in a large majority of these plants, is a prolongation of the tubular petiole, which itself curves over into a dome-shaped lid, *h*, that projects far enough over the mouth to make the opening, *m*, fall directly beneath the apex of the dome. The dome continues to curve around and inward till only a small orifice is left between its lower edges and the inner wall of the tube, *m*. Still further is this orifice guarded by the leaf proper, *l*, which springs from the outer edge of the opening, diverging rapidly into two long narrow wings. The tube itself is green in its lower portion; toward the upper, the spaces between the green veining of the leaf are of a translucent yellow, something like the white spots in the bright net-work of *Sarracenia*.

This makes the dome-shaped portion of the pitcher look, to the casual observer, "like a ripe jargonelle pear." The flap which flares out from the mouth is

FIG. 73. DARLINGTONIA CALIFORNICA.

p, Petiole; *w*, wing; *m*, mouth; *h*, hood; *l*, swallow-tailed appendage; pitcher cut off; *f*, flower; *o*, opening for admission of insects; *d*, open-mouthed pitcher. [After Curtis.]

brilliantly colored,—of a dusky orange veined with red, like the petal of a tulip, or arbutilon. On the inner surface of this appendage are multitudes of short, stiff hairs pointing toward the mouth. Down the outer surface, opposite the midrib, *a*, *a*, runs a longitudinal wing, *w*, like that of *Sarracenia*; this wing separates into two at its base, which is another clue to the fact that it is morphologically the doubling back of the two otherwise adherent lateral edges of the petiole, as we have seen it to be in *Heliamphora*. There is some evidence to prove that this wing is supplied with honey glands, and serves as a lure. The swallow-tailed appendage is, however, in the case of *Darlingtonia*, the real lure. Its inner surface is found to possess honey-secreting glands, which are still more frequent upon the inner surface of the hood; but this, of course, could attract and secure only flying insects. An examination of the insect remains in *Darlingtonia* proves that it catches almost entirely flying insects, while *Sarracenia* lives principally upon ants and other prey, which crawl up by the way of the wing and into the orifice.

The most singular fact in regard to the *Darlingtonia* is that in its own person, at different stages of its development, it bears pitcher-shaped leaves, repre-

senting both the open- and the close-mouthed tubes found in the two kinds of *Sarracenia*. [Fig. 72, *d*, open-mouthed; *a*, close-mouthed pitchers.] These small tubes, as may be seen in the figure, have very oblique open mouths, the upper lip of which is drawn out into a long, slender scarlet hood, that does not close the mouth. The slight twist in the tubes causes them to face in every direction; these tubes, which correspond to the open-mouthed pitchers of *Sarracenia purpura*, catch only small insects. As the plant grows older, however, it bears much larger sub-erect pitchers, A, of which the description and figure have been given. The flower of the *Darlingtonia* is solitary, growing upon a tall stem about four

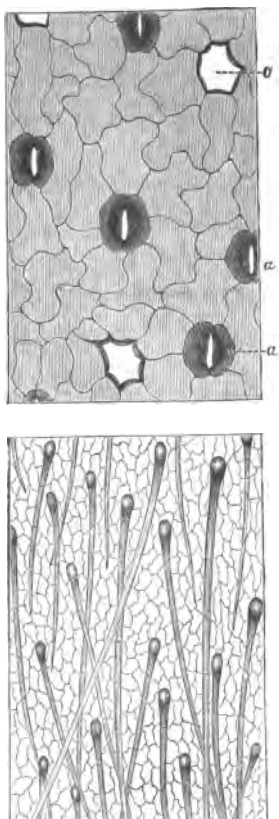


FIG. 74. DARLINGTONIA CALIFORNICA. A, Glandular surface; B, hairs of detentive postion. [From Nature.]

or five feet high. In the figure, the flower [Fig. 72, *f*] will be seen with a curious opening, *o*, between its adjacent petals. From the position of the pistil, which hangs in the centre of a dependent bell-shaped ovary, like its clapper, and of the stamens around and above it, it is impossible that the flower should fertilize itself; the pollen could, by no possibility, fall upon its own stigma; and Hooker, in his address before the British Association, in 1874, suggests a close connection between the floral and foliar arrangement of the plant. "Looking at a flowering specimen of *Darlingtonia*," he says, "I was struck with a remarkable analogy between the arrangement and coloring of the leaf and of the flower. The petals are as highly colored as the flap of the pitcher, and between each pair of petals is a hole [Fig. 72, *o*] leading to the stamens and the stigma. Turning to the pitcher, the relation of its flap to its entrance is somewhat similar. Now, we know that colored petals are especially attractive organs, and that the object of their color is to bring insects to feed on their pollen or nectar, and in this case, by means of the hole, to fertilize the flower; that the object of the flap and its sugar is also to attract insects, but with a very different result, cannot be doubted. It is hence conceiv-

able that this marvellous plant lures insects to its flowers for one object, and feeds them while it uses them to fertilize itself, and that, when this is accomplished, some of its benefactors are thereafter lured to its pitchers, for the sake of feeding itself."

Besides their intrinsic interest, these wonderful plants possess a special value, as a new link in the chain of physical truth, which now in our ignorance we may fear will lead us into darkness and doubt, but which, when it is perfected, can do no other than bind the frailest and meanest life with the omnipotent and glorious Life-giver; which, however meaningless it may seem now, will assuredly—when we come to know as we are known—prove to be the marvellous chain, whose every link has been forged by infinite patience and love, for the binding together of things material with things spiritual,—of earth with heaven.

CHAPTER X.

INSECTIVOROUS PLANTS

THE strong interest felt by the popular mind in scientific research is becoming every day more and more manifest. Since the publication of Darwin's last book on "Insectivorous Plants," one man, if no more (so the London newspapers tell us), has driven a thriving trade by selling on London Bridge the *Drosera rotundifolia.* So long as the sundew was a common sundew and nothing more, it had to submit to be treated as an insignificant weed; but when its merits as a carnivorous plant were made known, it acquired new dignity and interest.

When the millennium comes, perhaps we shall find that the powerful instinct which prompts us in these evil days to pry into our neighbors' affairs and so do incalculable mischief, has its legitimate satisfaction in exploring the wonders and mysteries of that humble life about us, which has no hidden anguish to cover with smiles,—no closeted skeleton to conceal.

The distinguishing feature which characterizes modern science is not so much that she reaches out toward the new, the wonderful, the beautiful, and brings it within the ken of her few chosen votaries, as that she is penetrating downward into the popular heart and mind, unravelling the golden mysteries of truth for us who are not her high-priests, but are only of those who stand humbly afar off and desire to know. There is a wonderful levelling power in the forces at work in modern society. The truth given to the world nearly twenty centuries ago has a secular as well as a religious side to it. Not only have the poor the Gospel preached to them, but this same Gospel has opened a way through the otherwise impenetrable darkness of human sin and degradation for other light to shine. The dawn of modern civilization which broke upon the Judean hills eighteen hundred years ago is "shining more and more unto the perfect day." Then the great wall of partition set up by man's pride and dogmatism received the blow which shook it to its foundation, and it has ever since been crumbling quietly away.

Now that scientific truth is working its way downward and permeating all classes of society, some slight disturbance is naturally created;—a little

knowledge is truly a dangerous thing, not because it is knowledge, but because it is so little. And yet even this little has its use,—it is essential as an entering wedge for more. Darwin, whose name is the battle-cry of one of the opposing forces, is a man possessing such qualities of mind as might well be imitated by those who denounce him as the prince of atheists He is an observer of facts, who is able to brush away from before his eyes the mists of traditional belief, who looks right into the heart of physical truth, and sees things as they are. There is frequently a judicial fairness about his statement of such facts as strongly militate against his own theory, which is beyond all praise. Where the issue should be made with him is in the magnitude of his inferences. However strongly we may and do dissent from his conclusions,—taken as a whole,—we cannot do less than make grateful acknowledgment of the treasures of fact which he has given to the world. The invectives hurled at his head by the "Christian world" are not arguments, and they have lost their power as mere anathemas. They look far more like the passionate protests of a subtle unbelief trying to prop up its wavering faith by the violence of its expression, than the calm utterances of a truly Christian faith.

To Darwin, certainly, we owe much of our knowledge of those plants which may be called with perfect accuracy, insectivorous, and to him, therefore, we make acknowledgment.

The pitcher plants and the *Utricularias*, as we have seen, derive their nutriment from organized matter, by absorbing the results of its decomposition. The plants now to be considered are higher in the scale of being, they possess organs for a true digestion and assimilation, and exhibit, in addition to these peculiarities, other phenomena which have been supposed to be confined to the animal world.

The first of these plants which may be called truly insectivorous is a tiny aquatic plant found in Europe, Asia, and Australia; no mention is made in Darwin's book of any American variety. A search of many days through a number of botanical periodicals has brought to light no single fact in addition to what Darwin has recorded. The botanists all seem to be on excellent terms with the *Aldrovanda;* they allude to it in their classifications, and use it as illustration with an easy and off-hand familiarity which is very tantalizing to one who is seeking information; but with the exception of Cohn and Darwin, they tell us absolutely nothing about its life history.

According to Darwin, then, and to Cohn, the *Aldrovanda* is a water plant, destitute of roots and floating freely in its native element; the petioles or leaf-stalks, grow out radially from the stem; these are broad, and terminate in from four to six slightly divergent spines, each tipped with a stiff bristle. The leaf grows in the midst of these projections; it is bilobed, and the two lobes stand apart about as far as the two valves of a living mussel-shell. The hinge of the two valves is the midrib, and this projects somewhat beyond the leaf itself, and is also armed with a bristle. When the two valves are opened and pressed flat, the impression to the eye is of two circles so cutting each other that the circumference of each passes through the centre of the other. The midrib forms the common chord which subtends the four arcs. The overlapping portion of the circles is seen to be darker than the other, and between these two parts of each lobe there is a wide difference of structure and function. The darker segment of each lobe possesses the digestive and muscular apparatus of the higher species of insectivorous plants, while the lighter crescent-shaped portion is covered with absorbent quadrifid processes with which we have already become familiar in the *Utricularias*.

It is certainly very wonderful that we should find in an obscure and insignificant plant like the *Aldrovanda*, on one tiny leaf a perfect representative of each of the two kinds of carnivorous plants, with the peculiar and delicate apparatus of each for the appropriation of organic matter. The *Aldrovanda* supplies the link between the two distinct modes of nutrition in this class of plants, as the class supplies the link between the two great kingdoms of organic nature. The absorption of decomposed matter, performed by the quadrifid processes on the outer portion of the leaf, has already been described in the case of the *Utricularia*. The digestive process of the glands upon the inner portion will appear as we study the *Drosera* and *Dionæa*, to which it bears a close resemblance, especially to the latter. Indeed, Darwin speaks of the *Aldrovanda* as a miniature aquatic *Dionæa*.

The *Drosera rotundifolia* [Fig. 75], or sundew, is a common weed, found in poor and peaty soil which can sustain only the sphagnum mosses, and such vegetation as derive little nutriment from the soil. It bears from two to six leaves, which generally spread out radially and horizontally from the base of the flower-bearing stem. The leaves, which are

rounded and slightly concave, are covered on the whole upper surface with what appears to be glandular hairs, each of which bears upon its tip a a drop of

FIG. 75. DROSERA ROTUNDIFOLIA. [AFTER LINDLEY.]

dew. The leaf itself and its pedicel are green; these hairs, or tentacles, *t*, as Darwin calls them, from their resemblance in function to the tentacles of polyps, are of a purple color. On the central portion of the leaf or disk, the tentacles are

FIG. 76. LEAF OF DROSERA ROTUNDIFOLIA (EIGHT DIAMS.). [FROM NATURE.]

short, and stand upright, and their pedicels are green; toward the edges they become longer, and are more inclined outward, and their pedicels are purple. On the extreme margin they are still longer and bend backward. [See Fig. 76.]

The tentacles are not like ordinary trichomes or hairs which, as we have seen, belong to the epidermal system, but they seem to be prolongations of the leaf itself. Bundles of fibro-vascular tissue extend from the leaf up into the tentacles, and in the glandular swellings at the end a bundle of spiral vessels may be very easily seen under moderate powers. The glands, except those borne by the marginal tentacles, are oval [see Fig. 77], about $\frac{1}{600}$ of an inch in length, and of about equal size. They are composed, as the drawing shows, of a bundle of spiral tissue surrounded by several layers of cells, the inner ones decidedly elongated. These spirals are not air-conducting passages, as is usual, but secretory vessels, it would seem, though not essential to the performance of this office, as they are wanting in the glands of some other genera of the *Droseraceæ*. The marginal tentacles differ somewhat from the others in having elongated glands and in being less irritable, though they do not show any essential variation. The whole leaf, above and below, is covered with small trichomes having a cone-shaped pedicel surmounted by two, three, or four rounded cells, containing much protoplasm. These papillæ [Fig. 76, p. 212] do not secrete, but they absorb readily, and aid in the assimilative process of the plant.

If a small object be placed upon the centre of a leaf, an impulse is transmitted radially to all the tentacles; the nearer ones are first reached, and begin slowly to bend toward the centre, afterward those farther away are similarly affected, until, finally, every one of the hundred or more tentacles of the leaf closely clasps the object. This inflection takes from one to five hours or more for its completion; the difference in time depending upon many circumstances,—on the vigor and age of the leaf, on the size and nature of the object, on the temperature of the air, and upon the present condition of the leaf in consequence of a recent inflection.

If the glands be repeatedly touched, if drops of certain fluids are placed upon the disk, or if it be immersed in certain solutions, inflection is induced. In bending over to clasp an object, the marginal tentacles—which normally bend backward—sometimes sweep through an arc of 180°. The whole tentacle does not bend, but only a portion of the pedicel just above the base. When an object, which excites the leaf to become inflected is placed in the centre of the disk, the short middle tentacles do not move; if, however, it be placed to either side of the medial line, they bend over toward it and clasp it.

If a nutritious object be placed upon one of the marginal glands, or an insect alight there, that tentacle alone bends, till the captive is deposited in the centre of the disk, and then a radial impulse is sent out which causes all the tentacles of the leaf to bend over and clasp it. The object, it will be understood, is held fast by the viscid secretion of the glands.

Not only do these tentacles themselves bend over, but when any strongly exciting liquid like milk is placed upon the middle of the disk the whole blade becomes incurved and forms a tiny cup. At times the edges curve inward and upward equally all around, but usually the apex and two sides turn upward forming a triangular vessel. The time during which a leaf remains incurved, or the tentacles remain inflected over an object, depends somewhat upon the vigor of the leaf and the temperature of the weather. But by far the most influential force in determining this time, is the nature of the object causing inflection. If the captured prey is capable of yielding nutriment to the plant, the leaf remains much longer inflected than when the object is innutritious. After an interval of from one to seven days the tentacles re-expand and the leaf is again ready for action.

The natural prey of these leaves are, of course, insects, though they may be fed with meat, albumen, drops of various liquids, such as strong infusions of raw meat, cabbage, peas, etc., and they have been known to die of something akin to dyspepsia, from partaking of too much cheese. Every gland is surrounded by a drop of a viscous pellucid substance which it secretes; the heat of the sun, which dries the drops of genuine dew, has no effect upon this secretion unless it be to induce a freer flow. To this fact the plant owes its popular and poetic name of sundew. Any insect which chances to alight upon the gland-bearing leaf is caught and held fast by the viscid secretion, and its fate is sealed; as soon as it is fairly clasped by the incurved tentacles, the glands pour forth a new secretion, which closes the spiracles and the victim dies. This second secretion, as we shall see, differs very much from that which secured its prey, for it is a true digestive fluid.

Any minute particle of matter, which penetrates the viscid secretion, and comes into actual contact with the gland produces inflection, but unless it touches the gland itself, no effect is produced. If a gland be touched once or twice with considerable force, the pedicel does not bend; repeated touches,

however, even when lightly made, produce inflection. Though the feet of the most delicate insect, after resting for a few moments on the gland, cause the tentacle to bend over, repeated drops of rain, it is found, induce no movement.

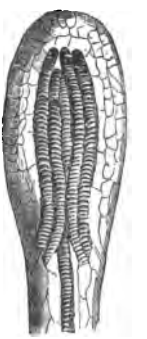


FIG. 77. TENTACLE OF D. ROTUNDIFOLIA. (100 diams.). [From Nature.]

A very curious interior molecular movement so generally accompanies inflection that it will not be out of place to mention it here. When the motor impulse is communicated to the bending portion of the pedicel of a tentacle, and inflection begins to manifest itself, a change takes place in the cells—a change which is clearly manifest under a low power, and may even be detected by the naked eye. Previous to the excitement of the tentacle its cells seem filled with a homogeneous purple fluid; sometimes not more than ten seconds after excitation, the cells of the gland become cloudy. Under a very high power, this change is seen to be due to the fact that small purple granules appear within each cell which aggregate into minute spheres, and these, in their turn, coalesce into larger masses of purple protoplasm, suspended in a colorless fluid. These pro-

toplasmic masses are continually changing shape, dividing and coalescing, and spontaneously moving. If the excitation of the gland has been very great, the aggregation extends down through every cell of the tentacle; during this process the steady flow of a protoplasmic current, before described as cyclosis, goes on around the inner surface of every cell wall. The stimulants which produce inflection also induce aggregation; $\frac{1}{184.400}$ of a grain of the carbonate of ammonia administered to a gland has been known to produce distinct movement and aggregation.

The effect is the same whether the gland be excited directly by repeated touches, or by the presence of an exciting body, or indirectly, by the transmitted impulse from other and distant glands. The exciting influence which produces inflection cannot be identical with the direct cause of aggregation; because, even when the impulse comes from another part of the leaf, and the motor power must run up the tentacles to which it is transmitted, the aggregation invariably begins at the cells of the glands and runs down. As long as the tentacles remain closed aggregation is present; when they re-expand, the little masses of protoplasm dissolve, and the cells seem again filled with a homogeneous pur-

ple fluid. As this curious effect may be induced by the presence of bits of glass, etc., it is, of course, entirely independent of absorption. "Physiologists," says Darwin, "believe that when a nerve is touched, and it transmits an influence to other parts of the nervous system, a molecular change is induced in it, though not visible to us. Therefore it is a very interesting spectacle to watch the effects on the cells of a gland, of the pressure of a bit of hair, weighing only $\frac{1}{78,700}$ of a grain, and largely supported by the dense secretions; for this excessively slight pressure soon causes a visible change in the protoplasm, which change is transmitted down the whole length of the tentacle, giving it at last a mottled appearance, distinguishable even by the naked eye." The leaves of *Drosera* detect with the utmost quickness and the most unfailing certainty the presence of nitrogen. At the time when this power was discovered by Darwin, the delicacy of the test was unrivalled. Now he says with a little crestfallen air: "The spectroscope has altogether beaten *Drosera*," for it can detect the presence of $\frac{1}{200,000,000}$ of a grain of iodine,—while *Drosera* could do no more than announce the $\frac{1}{20,000,000}$ of a grain of phosphate of ammonia.

When any substance yielding nitrogen is placed upon the *Drosera* disk, a liquid is secreted and poured out over it from the glands, which differ from the drops already formed upon its surface. This change in the quantity and quality of the secretion is effected in all the glands before the outermost ones have been fully inflected; it is, therefore, not the direct result of absorption, but of a transmitted influence. Physiologists tell us that when the stomach of an animal is mechanically irritated, it secretes an acid; but that it does not secrete its proper ferment, pepsin, till the absorption of certain nutritious substances has taken place. The experiments upon *Drosera* show a precisely analogous process. As soon as the glands are excited, an acid is secreted; but it is only after absorption that the true gastric fluid makes its appearance. That this secretion "contains a ferment which acts only in the presence of an acid, on solid animal matter," as animal pepsin does, has been clearly proved. While the process of digestion by the leaf is going on, the addition of a minute portion of alkaline matter is found to arrest it at once; while the addition of acid sets it going again.

The identical substances are found to be acted

upon, in the same way and to the same degree, by the gastric fluid of *Drosera*, as they are by animal pepsin. Cartilage, bone, even the enamel from teeth, were experimented upon, and it was found were dissolved by it, as well as certain vegetable substances, such as the stored-up matter of living seed, pollen grains, and the fragments of seedlings. Various experiments were made by Mr. Darwin to ascertain the effects produced by different salts. He found that $\frac{1}{20,000}$ of a grain of phosphate of ammonia caused a marginal tentacle to sweep through an arc of 180°. The sensitiveness, in this case, is greater than that found in the most sensitive organs of the human body. Many curious facts came to light under this close investigation. Camphor, it was found, is a violent stimulant; the poison of the cobra occasioned only slight protoplasmic changes, while liquid alcohol produced no effect whatever. In small doses the fumes of camphor, alcohol, and chloroform, threw the plant into a stupor. Carbonic acid is also a narcotic, which fact offers a curious confirmation of the lately determined point that plants exhale, *as the result of true respiration*, the same gas as is given out by the breathing of animals.

The sensitiveness of the *Drosera* leaf appears to

be wholly confined to the glands. Unless the gland which is excited be upon a marginal tentacle, the object, or touch, that induces its own inflection also causes a radial influence to be sent outward from its base as a centre that affects, first, the nearest tentacles, and in succession, those which are farther and farther off. This impulse does not follow the fibro-vascular bundles, whose arrangements may be seen in Figure 76, *f;* but its course seems to be determined by the form and position of the parenchymal cells of the base of the tentacles themselves and the surrounding tissue. The cells are elongated in the pedicels of the glands; they are arranged radially about the bases of the tentacles, and are longer in the longitudinal direction of the leaf. Aggregation may be seen to be obstructed by every cross division of the cell wall; the motor impulse is probably hindered in the same way, for it always travels most quickly in the direction where there is the least obstruction in the form of cell walls.

When the bending portion of a pedicel receives the impulse from its own gland, it always becomes inflected toward the centre of the leaf, and so all the glands, if immersed in any exciting fluid, turn toward the centre. When, however, the exciting substance

is placed on any other portion of the leaf, the motor impulse is so transmitted radially from the point touched that all the glands turn toward it as a centre. The motor impulse, as it ascends the pedicels of adjacent tentacles, immediately acts upon the bending portion, without first ascending to the glands, and then being transmitted downward. Some other impulse is, however, transmitted to the glands, for they begin secreting an acid substance, and the glands send back toward the bases of the pedicel that subtle force which induces aggregation. This is the only case of any thing analogous to the reflex action of the nerve-centres of animals known in the vegetable world.

The mechanism of the movements is not well understood; while the tentacle is bent—and it has been made to curve around a complete circumference—no folds or wrinkles can be seen in the concave portion of the bending part. It is known that when inflection takes place, a portion of the fluids belonging to the cells in the concave side goes over to the convex. It is supposed that the molecules of the cell walls on the concave side of the pedicel undergo a process not unlike that of the aggregation of the cell contents.

FIG. 78. DIONÆA MUSCIPULA. [AFTER LINDLEY.]

The many experiments made upon the *Drosera* lead to the conclusion that its tiny rootlets perform for it only the office of imbibing moisture, while its food is in part supplied by the atmosphere, and in part by the animal matter it truly digests.

FIG. 79. LOBE OF DIONÆA. [FROM NATURE.]

There are a number of other varieties of the *Droseraceæ*. One, the *Drosera binata*, is an Australian plant, and has leaves which, with their footstalks, measure twenty-seven inches in length. True to its Australian traditions, it differs greatly from its foreign cousins. There are perfectly developed tentacles on the back of the leaf, which are capable of secretion, absorption, and aggregation, but not of inflection. On both surfaces of this variety are well-developed sessile (seated) glands, which secrete only after the absorption of some nitrogenous substance. This variety forms the connecting link between *Drosera* and *Drosophyllum*, possessing the organs of both.

The *Drosophyllum* has been found, so far, only in Portugal and Morocco. The leaves are narrow, concave above, and several inches long. They are covered with stalked, mushroom-shaped tentacles, and quantities of small round, or oval, sessile glands. Internally the tentacles and glands are alike, but they are fitted to perform entirely different functions. The tentacles have no power of flexure; the substance which they secrete, unlike that of *Drosera*, is easily detached from the gland, and for that very reason is specially adapted to its peculiar mode of capture. The two secretions,—of the viscid acid and of the pepsin,—which in *Drosera* are performed successively by a single gland, are performed in *Drosophyllum* by two separate organs,—the mushroom-shaped tentacles secreting the first, and the sessile glands the second of these fluids. The latter glands secrete spontaneously their peculiar substance, which is sufficiently fluid to roll off their rounded tops at a touch. An insect alights, and rolls off, carrying with it the viscid drop which effectively clogs its wings and legs, so that it lies helpless upon the leaf below. The lower glands, now, being excited by the presence of nitrogenous matter, begin to secrete their pepsin, and the food is finally digested. The gastric fluid

secreted by all of the *Droseraceæ*, it may be mentioned here, is an antiseptic,—the substances submitted to its action always disappearing, as they do

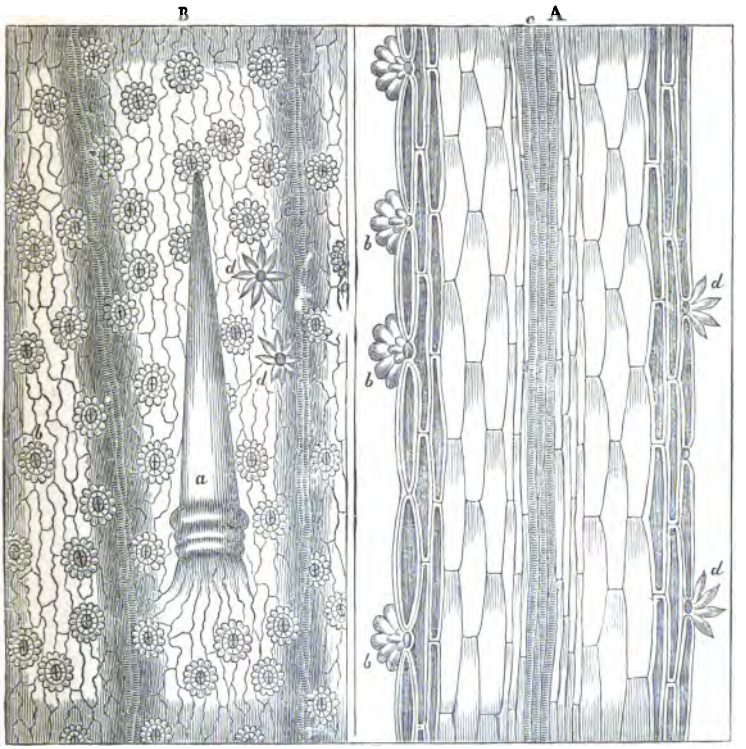


FIG. 80.

A, Glandular texture of *Dionæa* leaf, seen in section; *b*, *b*, glands on upper surface; *d*, *d*, stellate hairs on lower surface. (About 150 diams.) B, Glandular surface of *Dionæa* leaf, seen from above; *b*, digestive glands; *d*, stellate hairs; *a*, sensitive filament. (100 diams.) [After Nature.]

in animal pepsin, without showing any signs of decomposition.

The *Dionæa*, or Venus' fly-trap, is found in great quantities in parts of this country. It presents many points of similarity, and as many of difference, when compared with *Drosera*. [See Fig. 78.] It possesses, like the *Drosera*, very small roots. As the plant has been successfully grown in wet moss, they probably serve the same purpose, and are useful only for imbibing moisture. The footstalk broadens out into a leaf-shaped expansion of tissue, *a*, *a*, *a*, at the end of which a two-lobed leaf is found. The lobes curve upward and outward convexly at an angle of less than 90° from each other; the lobes terminate on their outer edge in a row of sharp projecting points, into each of which a bundle of spiral vessels extends. On the upper surface of each there are three delicate filaments triangularly placed. [See Fig. 79, *b*, *b*; also Fig. 80, B, *a*.] Occasionally there are more or less; but the usual number is three. These filaments seem to be the only sensitive part of the lobes; though their sensitiveness they show, not by their own movements, but by that of the lobe on which they are placed. The upper surface is thickly covered with glands, sessile upon the leaf,

with a convex upper surface. [See Fig. 82, *a*, *b* ; Fig. 80, A, *b*, B, *b*.] These glands secrete, but only after having absorbed some nutritious substance. Minute projections, having eight arms, stellate

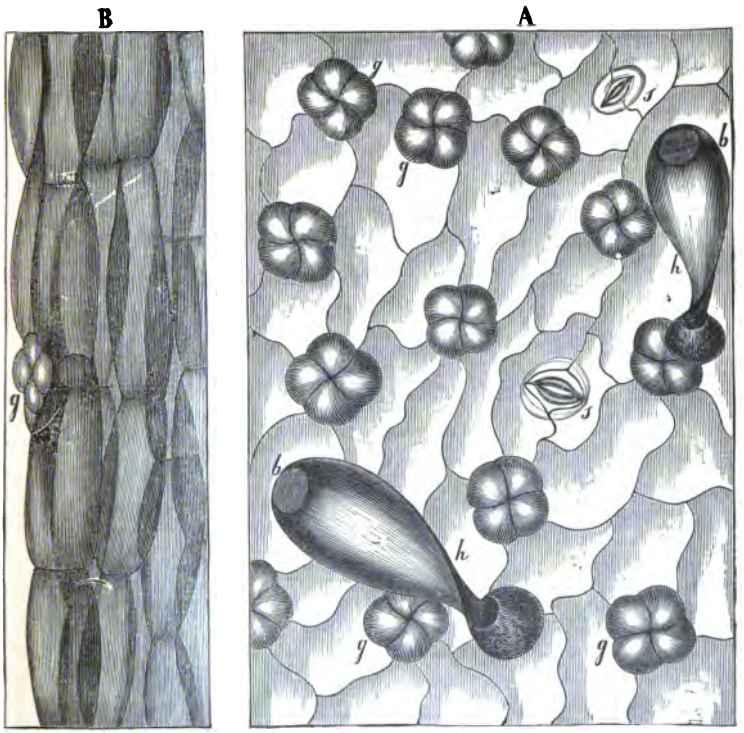


Fig. 81.

A, *Pinguicula*, glandular surface of leaf ; *g*, glands ; *h*, hairs ; *b*, base of hairs ; *s*, stomata. B, Section of *Pinguicula* leaf ; *g*, glands. [From Nature.]

hairs, are found thickly studding the outer surface of the lobes. [Fig. 80, B, *d*.] The whole processes of movement and digestion are wonderfully and beautifully correlated. The continued pressure,

FIG. 82. GLANDS.
a, Top view ; *b*, side view ; *c*, stellate hairs. [After Lindley.]

however slight, which causes the slow inflection of the *Drosera* tentacles, after the first touch, has no effect upon *Dionæa*. The *Drosera* captures its prey by means of its viscid secretion, and the pressure caused by the struggles of the insect causes inflection, which it accomplishes quite at its leisure. *Dionæa*, having no secretion, secures its prey by instantly closing upon it. The filaments, therefore, which cause the lobes to close instantly at the lightest touch, are comparatively indifferent to prolonged pressure. These filaments have nothing whatever to do with the digestive process; they are merely the sentinels, on guard to signal at the approach of a victim.

Inorganic bodies placed upon the lobes, unless they

touch the filaments, do not cause them to close; organic bodies when moistened and placed upon the leaf cause it, after absorption has taken place, to close slowly. The lobes may be made to close over either organic or inorganic matter, but with a difference. When an inorganic substance is placed upon the leaf and the filament touched, the leaf closes leaving a hollow chamber, the spines crossing and interlocking as in Fig. 78, *b*. When, however, an organic substance is placed upon the leaf, both lobes press against it and against each other, through their whole extent, with a force sufficient to perceptibly flatten a cube of the white of hard-boiled egg, upon which they have shut. A corresponding projection may be plainly seen on the outside of the lobes after they have fairly closed over their prey; no secretion takes place unless absorption begins. When a substance possessing no nutritious properties is enclosed, the glands are not excited to secretion, and the lobes soon reopen, disclosing the object perfectly dry. If they close over a very minute organic object, it is allowed to escape between the interlocking teeth,—the play, *Dionæa* thinking, not being worth the candle. When, however, the organic object is large enough to be worth their

while, the lobes flatten themselves against it, the spines standing upright and parallel instead of interlocking. The glands touched by the nitrogenous substance begin to secrete as soon as absorption has taken place. The digestive fluid containing the nitrogenous matter is then forced by capillary attraction up between the flattened lobes so closely pressed together; in this way, all the glands are excited to secretion,—and the prey is digested. The two movements induced by a touch upon the sensitive filaments and by secretion, are very wonderful in their entire adaptiveness to the purposes which they subserve. A touch from any useless substance, unless it chance to be upon one of the sensitive filaments, produces no effect, while the presence of a nutritious one on any portion of the leaf causes it to close. After a short interval, with no exhaustion of the gastric fluid, the leaves unclose, unless they have captured something which will help to maintain life, while they remain closed over nutritious matter, instead of twenty-four hours as *Drosera*, for fifteen, twenty-four, or even thirty-five days. The power of secretion and absorption belongs to the sessile glands [Fig. 80, A, *b*, B, *b*] which are an epidermal outgrowth, and whose appearance

under the microscope as the focus is slowly changed is strongly suggestive of their being morphologically stomata, which have been modified to serve another purpose.

In most cases when the *Dionæa* lobes reopen after their meal they are torpid, and no excitement of the glands or filaments is sufficient to induce movement. In this respect it differs greatly from *Drosera*, which is quite ready for another meal before its tentacles are fairly reopened.

The transmission of the motor impulse in *Dionæa* is very rapid ; a touch upon any one of the six filaments causes both lobes to close at once and simultaneously. The bending portion of the lobes is situated just above the midrib. Many beautiful and delicate experiments, made by Mr. Darwin, go to show that the curvature of the lobes is due to the contraction of the upper superficial layer of cells. The movement of these leaves is due to the same cause, at work in the contraction of the muscular tissue of animals. In both cases, a normal electrical current exists, which is disturbed upon any irritation of the organism. The *Aldrovanda*, of which mention has been made as a sort of aquatic *Dionæa*, has, upon the inner digestive portion of its leaf, numerous ses-

sile glands which assimilate food, and double-jointed, sensitive filaments which enable it to close upon its prey.

The *Pinguicula*, or common butterwort, offers one or two points of interest, as an insectivorous plant. A stem, bearing a cluster of purple flowers in general appearance very much like the sweet violet, springs from a rosette-like cluster of radical leaves. It bears about eight rather thick, oblong, light-green foliage leaves, which when young are deeply concave. The margins of the leaves are much incurved, and their upper surfaces are studded with glands *g*, stomata *s*, and extraordinary vase-shaped hairs *h*. [Fig. 81.] As in the other insectivorous plants, the roots are short and few in number. The principal point of interest about this plant is that it appears to derive more nutriment from vegetable organisms —from seed, spores, pollen grains, and even minute seedlings, which are found adhering to its leaves— than do the other members of the same family. In a paper published in 1847, by Planchon, in the *Annales des Sciences Naturelles*, the writer brings together almost every recognized species of the insectivorous plants, mentioning them by name, noticing the fact of their secretions and power of inflec-

tion, but never hinting at the fact that they appropriated the nutritious qualities of the insects they captured. It seems marvellous that an observer who could have noticed the obscure structural resemblances which bind these widely separated species together, should have overlooked the fact that they were insectivorous, especially when he himself supplies the clue to this discovery in the statement that the Lapps use the *Pinguicula* leaves to coagulate their milk, which causes it to set in a firm, sweet curd. This, it is very well known, is usually effected by rennet, a preparation made from the stomach of the calf, which of course contains animal pepsin.

The most beautiful of all the second class of this group of plants, is the superb *Nepenthes*, or pitcher plant of the East. [Fig. 83.] At the end of the true leaf there is a prolongation of its midrib, which sometimes grows to the length of a yard and bears upon its termination a vase-shaped growth. This pitcher is, according to Hooker, an enormously developed gland, like those which in a less conspicuous form are formed upon the tips of many leaves. In *Nepenthes ampullaria* the pitchers grow eighteen inches high—and the corrugated brim extends inside in

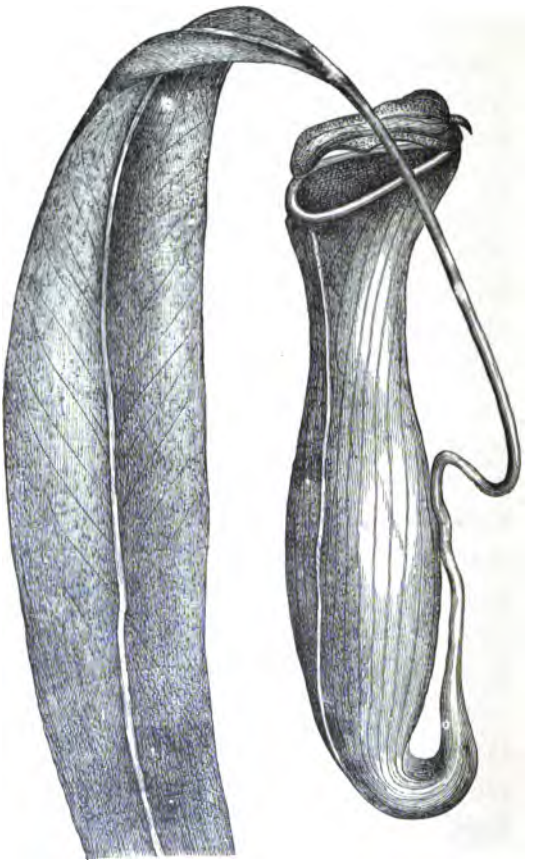


FIG. 83. NEPENTHES DISTILLATORIA.
Leaf and pitcher, natural size. [From Nature.]

the form of projecting incurved spines, which are strong enough to prevent the escape of any unwary bird which may thrust itself into the cavity in search of food. It would be hard to imagine any thing more wonderful and beautiful than the shape, the marking, and the coloring of this graceful pitcher—the broad corrugated brim flares off in a brilliant shaded rose-colored rim, bordering its whole mouth. Down the front run two fringed longitudinal wings, and above it stands a graceful leaf of brilliant colors, which sets off jauntily from the opening as if it had accepted the position, but had no notion of doing the work, of a vulgar lid. The inner surface, as in the *Sarraceniaceæ*, is divided into several portions: the attractive [Fig. 85], containing the honey glands; the conductive, being, according to Hooker, smooth and glassy, and covered with minute reniform excrescences; and the secretive, which is studded with innumerable glands of a very curious shape. [Fig. 84.]

Fig. 83 is a much smaller variety than the gigantic *N. ampullaria* described above. It is the *Nepenthes distillatoria*, a native of China, and kindly sent to me by Mr. Smith, of the Botanic Gardens, Washington, D. C. The drawing is life size, and the magnified portions, Figs. 84 and 85, were cut from this iden-

tical pitcher. An attempt was made to prepare one of the hundreds of ants which it was in the process of digesting, but the chitinous coats of even those which were most perfect had been made so tender

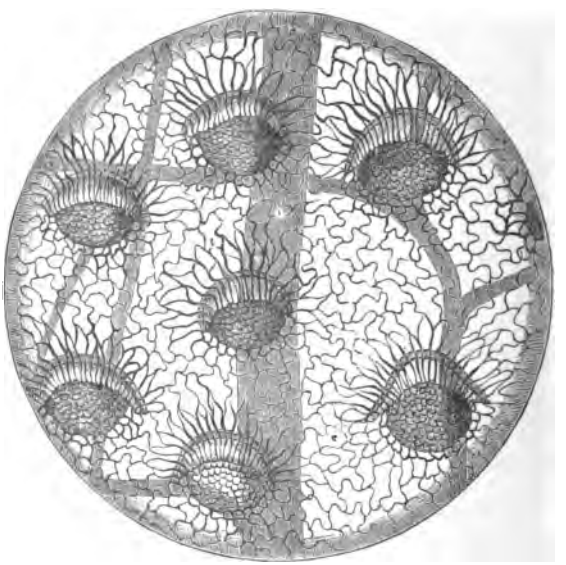


FIG. 84. NEPENTHES DISTILLATORIA.
Glands in stomach part of pitcher. (80 diams.). [From Nature.]

by the gastric fluid as to drop to pieces with a touch. The enormous crater-like gland, Fig. 85, A, was the only one found on a number of pieces cut from the upper portion of the pitcher. The branching hairs

B, *h*, glands *g*, *g*, and curious spirals *s*, seen in the figure, occur over the whole of the attractive surface.

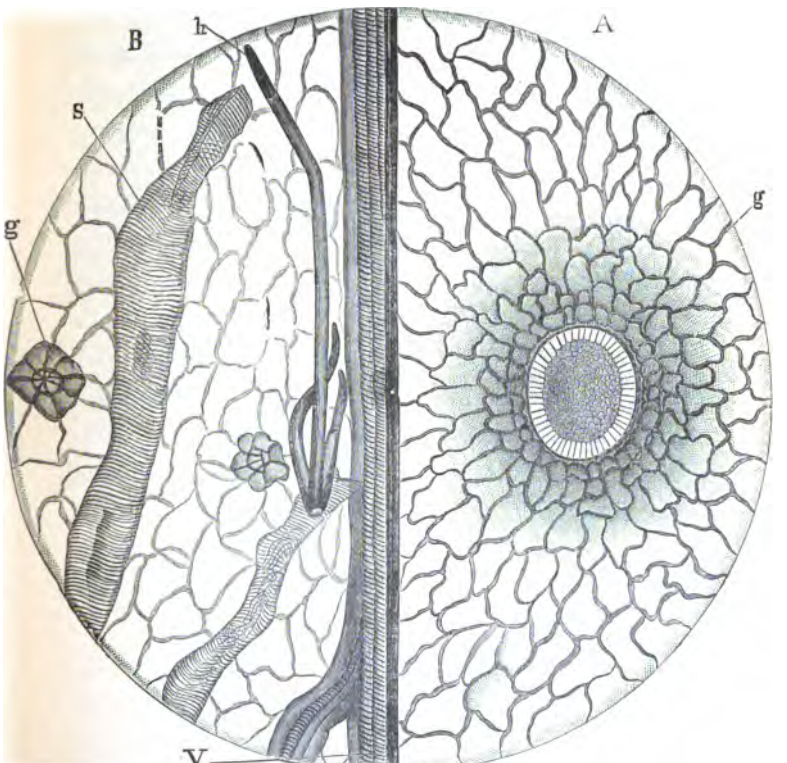


FIG. 85.

A, Single large gland, on upper and inner surface of pitcher of *N. distillatoria*. (250 diams.) [From Nature]. B, same surface; V, veins of leaf, with spirals; *s*, apparently spiral vessel; *g*, glands (honey glands); *h*, branching hair on external surface. (250 diams.) [From Nature.]

The secretive, or digestive, glands [Fig. 84], are large enough to be seen by the naked eye, as tiny specks regularly dotting the internal, lower surface of the pitcher. They all looked fairly brown with the insect remains they had accumulated or digested. In taking up the coloring matter, used in the preparation of vegetable tissues for the microscope, the iris part of these eye-shaped glands is the most brilliant blue, while the lid part and remainder of the tissues is a deep crimson-purple. The whole of the tissue was subjected to a mingled dose of logwood and aniline, and the selective power, by which one portion appropriated one color, and the other another, marks a radical difference in the tissues themselves.

Though in some respects the pitcher of *Nepenthes* is so much like that of *Sarracenia*, it belongs to the higher class of insectivorous plants; for it truly digests the food which it secures, and it also manifests the aggregation, which is found in *Drosera* and *Dionæa* during that process. Though in mere external form, we seem to have ended where we began, with a vegetable sac, which secures animal food and appropriates it. Yet this is far from true. The *Utricularia montana* has only modified roots; while one might almost say that *Nepenthes* has a modified

stomach. This last and most beautiful of the insectivorous plants serves to lead us into the very vestibule of that strange and inexplicable life, which the highest of us—on his physical side—shares with the humblest of the animal creation.

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